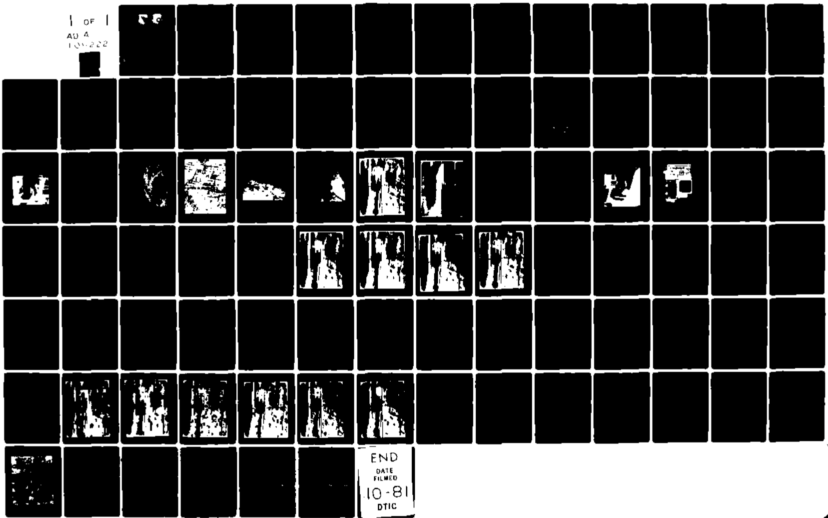
AD-A105 222 SYSTEM DEVELOPMENT CORP DAYTON OHIO F/G 17/2
EVALUATION OF ALTERNATIVE VIDEO IMAGERY PROCESSORS IN UNJAMMED --ETC(U)
AUG 81 R G MILLS, F T HUTSON, W B HARTMAN F33615-79-C-0505
UNCLASSIFIED AFAMRL-TR-81-45 NL



AFAMRL-TR-81-45

EVALUATION OF ALTERNATIVE VIDEO IMAGERY PROCESSORS IN UNJAMMED AND JAMMED ENVIRONMENTS IN TERMS OF OPERATOR PERFORMANCE IN A WEAPON DELIVERY SIMULATOR

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AUGUST 1981

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TECHNICAL REVIEW AND APPROVAL

AFAMRL-TR-81-45

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

CHARLES BATES, JR.
Chief
Human Engineering Division
Air Force Aerospace Medical Research Laboratory

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

11 REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: 18 AFAMRL TR-81-45
2. GOVT ACCESSION NO.: AD-A105222
3. RECIPIENT'S CATALOG NUMBER:

4. TITLE (and Subtitle): 6 EVALUATION OF ALTERNATIVE VIDEO IMAGERY PROCESSORS IN UNJAMMED AND JAMMED ENVIRONMENTS IN TERMS OF OPERATOR PERFORMANCE IN A WEAPON DELIVERY SIMULATOR.

5. TYPE OF REPORT & PERIOD COVERED: 9 Final rept.

6. PERFORMING ORG. REPORT NUMBER:

7. AUTHOR(s): 10 Robert G. Mills, Franklin T. Hutson*, Walter B. Hartman*, Edwin G. Meyer**, Herbert Navarro**, Constance M. Hoyland**, Robert R. Covelli**

8. CONTRACT OR GRANT NUMBER(s): 15 F33615-79-C-0505

9. PERFORMING ORGANIZATION NAME AND ADDRESS: Air Force Aerospace Medical Research Laboratory, Aerospace Medical Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio 45433

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 16 17 65727F, 2345-03-02

11. CONTROLLING OFFICE NAME AND ADDRESS:

12. REPORT DATE: 11 Aug[redacted]981

13. NUMBER OF PAGES: 84

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): 12 87

15. SECURITY CLASS. (of this report): UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

*with Air Force Wright Aeronautical Laboratory
**with System Development Corporation, 4134 Linden Avenue, Dayton, OH 45432

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Aeronautics
Imagery Processing
Sensors
Communications Systems
Man-Machine Relations
Operations, Strategy, Tactics
Navigation and Guidance
Combat Vehicles

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Five studies are reported in which the relative effectiveness of alternative video imagery processing techniques were evaluated. The processors were evaluated first in a simulated unjammed mode and then in a simulated jammed mode. The evaluations employed a GBU-15 electro-optical (TV) guided bomb, real-time simulator as a common testbed such that alternative techniques could be compared under identical conditions. Operators were required to find a pre-briefed target, lock-on to the target, perform lock-on adjustments (i.e., "fine tune" accuracy), and control, via hand control interface, the weapon on target.

Major conclusions of the studies were: (1) the processor employing the 1-dimensional cosine transform with differential pulse code modulation between the lines technique performed best in the unjammed mode, (2) the processor employing the 2-dimensional cosine transform with frame sample technique performed best in the jammed mode, (3) video display symbology should not be processed with imagery at data transmission rates of 300 kbs or less and display resolution of 128 lines or less, and (4) display resolution may be the most important processing parameter relative to the parameters of frame rate and the number of bits per picture element.

SUMMARY

Five studies are reported in which the relative effectiveness of alternative video imagery processing techniques were evaluated. The processors were evaluated first in a simulated unjammed mode and then in a simulated jammed mode. The processing techniques evaluated were (a) 1-dimensional cosine transform with differential pulse code modulation between the lines, (b) 2-dimensional cosine transform with frame sample, (c) 2-dimensional Hadamard transform based on internal full-frame storage, (d) 2-dimensional Hadamard transform based on external full-frame storage employing an external scan converter in combination with digital storage, and (e) adaptive 2-dimensional cosine transform.

The evaluations employed a GBU-15 electro-optical (TV) guided bomb, real-time simulator as a common testbed such that alternative techniques could be compared under identical conditions. Each test mission lasted 3 minutes during which the simulated vehicle was launched from an altitude of 20,000 feet at 100,000 feet ground range to target. Operators were required to find a pre-briefed target, lock-on to the target, perform lock-on adjustments (i.e., "fine tune" accuracy), and control, via hand control interface, the weapon on target. A variety of targets were employed having been obtained from oblique aerial photography. During each mission, a Flying Spot Scanner terrain simulator was used to generate video imagery by transitioning across six 9" x 9" frames of photography according to the vehicle's aeromodel and operator control inputs.

Major conclusions of the studies were (a) the processor employing the 1-dimensional cosine transform with differential pulse code modulation between the lines technique performed best *in the unjammed mode,* (b) the processor employing the 2-dimensional cosine transform with frame sample technique performed best *in the jammed mode,* (c) video display symbology should not be processed with imagery at data transmission rates of 300 kbs or less and display resolution of 128 lines or less, and (d) display resolution may be the most important processing parameter relative to the parameters of frame rate and the number of bits per picture element.

Major recommendations included: (a) a flyable version of a video, jam-resistant processor should employ the 2-dimensional cosine transform with frame sample processing technique and (b) further work is necessary to more thoroughly investigate bandwidth parameter trade-offs in jamming, effects of threat configurations, the physics of missions other than strictly TV guided bomb, other types of imagery (e.g., IR), etc.

PREFACE

Overall responsibility for this research program was with the Information Transmission Branch of the Avionics Laboratory (Charles C. Gauder, Branch Chief, AFWAL/AAA-D). Responsibility for developing the GBU-15 simulator employed in the program and conduct of the research studies performed was with the Crew Systems Effectiveness Branch of the Air Force Aerospace Medical Research Laboratory (Carroll N. Day, Branch Chief, AFAMRL/HEF). Richard D. Matson was the Project Engineer at AFWAL and Dr. Robert G. Mills was the Program Manager at AFAMRL. System Development Corporation was primarily responsible for simulator development and much of the supporting software. The authors also gratefully acknowledge the encouragement and support by Charles Bates, Jr., as Division Chief of the Human Engineering Division of AFAMRL. Others who significantly contributed to this program are listed below. Without their assistance and fine cooperation, this program would not have been a success.

AFAMRL: Nilss M. Aume
Dan Bridges
Dan Hughes

AFWAL: Anthony J. Rogers
Richard C. Sterling

System Development Corp: C. Kay Osborne

Systems Research Laboratories, Inc: Frederick R. Bodine
Teresa L. Marshall
Michael Masse
Michael R. Poole
Mark A. Theodoras
Julius A. Tieber

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1.0 *INTRODUCTION*

This report presents the results and conclusions of the Jam Resistant Imagery Transmission (JRIT) program conducted jointly by the Avionics Laboratory (AFAL) of the Air Force Wright Aeronautical Laboratories and by the Human Engineering Division of the Air Force Aerospace Medical Research Laboratory (AFAMRL).[1] The objective of the JRIT program is to evaluate the relative effectiveness of imagery bandwidth reduction/compression techniques in a simulated jamming environment while on-line to a common simulator testbed. It will be assumed in this report that the reader is generally familiar with the variety of jam-resistant imagery reduction/compression schemes being developed at the present time. For the unfamiliar reader or the reader wishing more information, greater detail can be obtained from AFWAL/AAAD-2 personnel.

1.1.0 The specific processing techniques evaluated in the JRIT program are as follows (see Table 1 for further definition):

1.1.1 1-dimensional cosine transform with differential pulse code modulation between the lines (1-DCDP).

1.1.2 2-dimensional cosine transform with frame sample (2-DCFS).

1.1.3 2-dimensional Hadamard transform based on internal full frame storage (2-DHIFSt).

1.1.4 2-dimensional Hadamard transform based on external full frame storage employing AFAL's scan converter (PEP-400) photomultiplier tubes in combination with digital storage (2-DHEFSt).

1.1.5 Adaptive 2-dimensional cosine transform (2-DAC).

It is noteworthy that one of the objectives of the JRIT program has been "applied" in nature, i.e., it was the intent of the investigation to identify a processing technique that could be packaged into a "flyable" version as quickly as possible. It is also noteworthy that severe budget cuts ended the program prematurely before a complete examination of the effects of jamming could be accomplished.

1.2.0 The thrust of this program has been to construct an experimental environment in which a variety of video image processing techniques could be evaluated under identical conditions. In constructing such an environment, it was considered essential that a testbed involving near real-world parameters be developed. Thus, it was required that the testbed include:

a. Operator visual/control performance in a dynamic display/control environment;

[1]There was an organizational symbol change during this program such that the former AFAL symbol for the Avionics Laboratory was changed. Since much of the material included in this report was prepared before the change, the symbol AFAL will continue to be used *only* in this report.

TABLE 1

Definition of Video Processors Evaluated in the JRIT Program

	Para 1.1.1 Time Domain/ Hybrid Compression System (1-DCDP)	Para 1.1.2 Time Domain/ Hybrid (2-DCFS)	Para 1.1.3 Two-Dimensional Binary (2-DHIFSt)	Para 1.1.4 Two-Dimensional Binary (2-DHEFSt)	Para 1.1.5 Two-Dimensional Discrete (2-DAC)
Design Approach	Cosine Transform with DPCM 32 Picture Elements/Block	20 Discrete Cosine Transform 8X8 Block Size Frame Sampling Verticle Stripes	20 Binary Hadamard Transform 8X8 Block Size	20 Binary Hadamard Transform 8X8 Block Size	20 Discrete Cosine Transform 16X16 Block Size
Resolutions*	512 X 480 256 X 240 128 X 120	512 X 480 256 X 240 128 X 120	512 X 480 256 X 240 128 X 120	512 X 480 256 X 240 128 X 120	512 X 480 256 X 240 128 X 120
Frame Rates*	7-1/2, 1-7/8, 15/32	7-1/2 1-7/8, 15/32	7-1/2, 3-3/4, 1-7/8, 15/32	7-1/2, 6, 4-2/7, 3, 2, 1, 1/2, 1/4	7-1/2, 6 4-2/7, 3, 2, 1, 1/2, 1/4
Quantization Levels* Bits/Pixel	1/2, 3/4, 1, 1-1/2, 2	1/2, 3/4, 1, 1-1/2, 2	1/2, 3/4, 1, 1-1/2, 2	1/2, 3/4, 1, 1-1/2, 2	1/4, 1/2, 1, 1-1/4, 1-1/2
Other Special Functions	Analog CTD (Charge Transfer Device) Cosine Transform Digital - DPCM	Digital Implementation	Digital Implementation	GFE Analog Scan Converter Used For Frame Rate Restoration	GFE Analog Scan Converter Used for Frame Rate Restoration

*Available Settings on the Equipment as Delivered to AFAL

b. The capability to evaluate different processing techniques involving different settings of the processing variables: resolution (number of lines), frame rate (number of frames per second), and number of bits per picture element (bits/pixel); and

c. A realistic jamming capability and scenario that would operate on processed imagery that had jam-resistant protection.

Previous studies in this area have all been limited with respect to one or more of the above requirements (Hershberger et al., 1976; Self et al., 1973; and Swistak, 1980). For example, these studies have generally employed static imagery or imagery limited in dynamic range, been limited to visual performance (e.g., target detection), employed one processing technique, or investigated the effect of a single processing variable (e.g., frame rate).

1.3.0 This report presents the results and conclusions of five studies. These studies are as follows:

1.3.1 1-DCDP versus 2-DCFS without jamming.

1.3.2 2-DHEFSt versus 2-DAC without jamming.

1.3.3 2-DHIFSt versus 2-DHEFSt without jamming.

1.3.4 1-DCDP versus 2-DCFS versus 2-DHIFSt versus 2-DHEFSt without jamming.

1.3.5 1-DCDP versus 2-DCFS versus 2-DHIFSt with jamming.

2.0 *RESEARCH APPROACH*

The research approach applied in this program has been to develop a GBU-15 electro-optical (TV) guided bomb simulator testbed whereby operator performance data collected under varying image processing and electronic jamming conditions can be obtained efficiently and inexpensively (i.e., relative to employing flight testing).

2.1.0 Under this approach, a fundamental assumption has been made: It is assumed that the performance of the simulator-operator combination will match that of its real-world system as closely as possible. However, the performance of the simulator-operator combination can be expected to deviate from the real-world analog system due to constraints on (a) the simulator (e.g., use of photography to simulate terrain), (b) the operators (e.g., non-use of Weapon System Officers (WSOs)), and (c) the real-world system (e.g., G-loads are placed on WSOs that are not present in the simulator).[2]

2.2.0 These deviations then make it risky to attempt to predict (or match) *absolute* performance of the real-world system. Although the above statement may be true, it is also true that *relative* performance results obtained in the simulator (e.g., A:B:C) should remain the same in the real-world system. Thus, if it is found in the simulator that operators perform better using compression equipment A than compression equipment B, *it can be expected that* the "A better than B" relation will hold in the real-world system.

2.3.0 The GBU-15 simulator consists of several major components to be described later. These are as follows:

2.3.1 Crewstation with hand control, B-52 display and switch panel located at AFAMRL.

2.3.2 Flying Spot Scanner (FSS) which employs photography for the generation of video located at AFAMRL.

2.3.3 GBU-15 Aeromodel.

2.3.4 Microwave Data Link interconnecting the AFAMRL and AFAL buildings.

2.3.5 Video compression/reconstruction processors located at AFAL.

2.3.6 A wideband spread spectrum video modulator/demodulator located at AFAL.

[2]To obtain an estimate of the deviation in performance between the GBU-15 simulator and its analog real-world system, one must measure the performance of operators in both systems against the same targets. Since this is not possible, the next best step is to measure the performance of WSOs in the simulator. This has not been done as yet; however, the simulator has been observed and favorable comments received from several persons with GBU-15 system experience. An estimate of the best accuracy that can be obtained by an operator in the simulator is discussed in Section 7, para 7.2.

2.3.7 The jamming simulator located at AFAL.

A block diagram of the overall GBU-15 simulator system is presented in Figure 1.

2.4.0 The general approach to evaluating alternative compression units was to collect data on operator performance in the GBU-15 simulator across a series of missions with a given processor on-line. Also, a series of baseline (no processing, clear imagery) missions were included among the evaluation missions. The baseline missions provided "calibration" data with which to determine an operator's true level of performance under the best set of conditions.

3.0 *GBU-15 SYSTEM*

3.1 *System Configuration*

The GBU-15 modular guided bomb with the electro-optical (EO) guidance system is launched from an F-4, F-111, or B-52 aircraft, and is guided by the Weapon System Officer (WSO) by TV images transmitted from the weapon seeker. The two basic weapon configurations are a planar wing configuration for longer glide ranges, and a cruciform wing configuration that provides greater maneuverability at shorter ranges. The details of the weapon mission, subsystems, and operating modes are described in the following paragraphs.

3.2 *GBU-15 Mission Profile*

3.2.1 The primary GBU-15 missions of interest for the JRIT studies are the TV guided indirect attacks. In these missions, the aircraft pilot acquires the general target area, releases the GBU-15 at the appropriate launch point, and executes a turn of either 70° or 135°. The 70° turn is used for a B-52 attack on ship targets, and the 135° turn is used for F-4 or F-111 attacks on ground-based targets. The 135° turn was assumed for the existing simulator.

Upon completion of the aircraft turn, the WSO acquires the TV video from the weapon seeker and controls the GBU-15 flight until impact. See Table 2 for operator actions. The details of the GBU-15 mission profile are elaborated in the following paragraphs.

3.2.2 The mission profile consists of four distinct phases or modes—captive, midcourse, transition, and terminal (See Figure 2). During the captive mode, the weapon is attached to the aircraft and is prepared for launch. Tests are made on the data link to confirm that the system is in proper working order. Just before the aircraft approaches the launch point, full power is applied to the data link and launch procedures are begun.

3.2.3 The launch is initiated by the depression of the bomb release button, which initiates the midcourse phase. After the GBU-15 has separated from the aircraft, the pilot executes his turn and maintains a position and look angle relative to the weapon. For the first 1.75 seconds after launch, the GBU will be in a partial guidance mode in which the guidance system controls the pitch rate, the yaw rate, and the roll

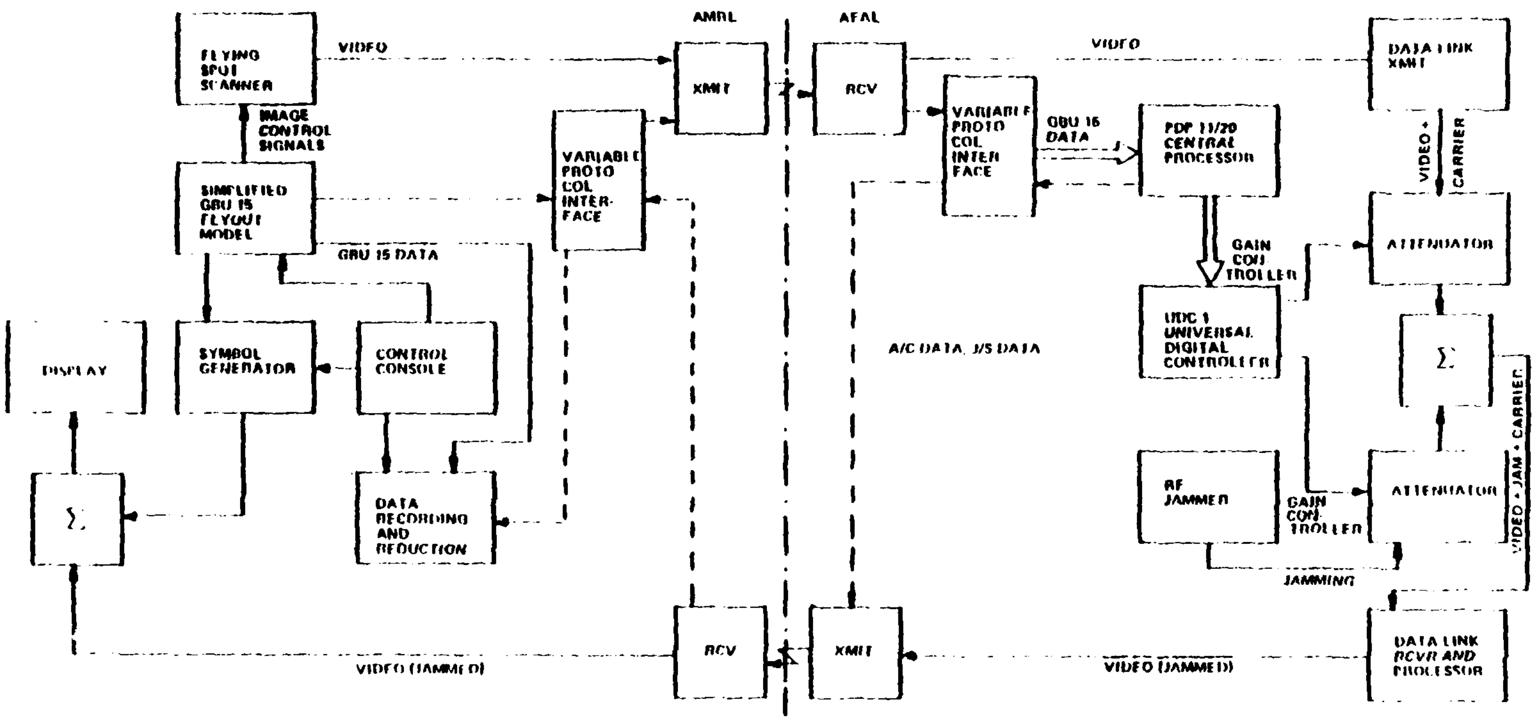


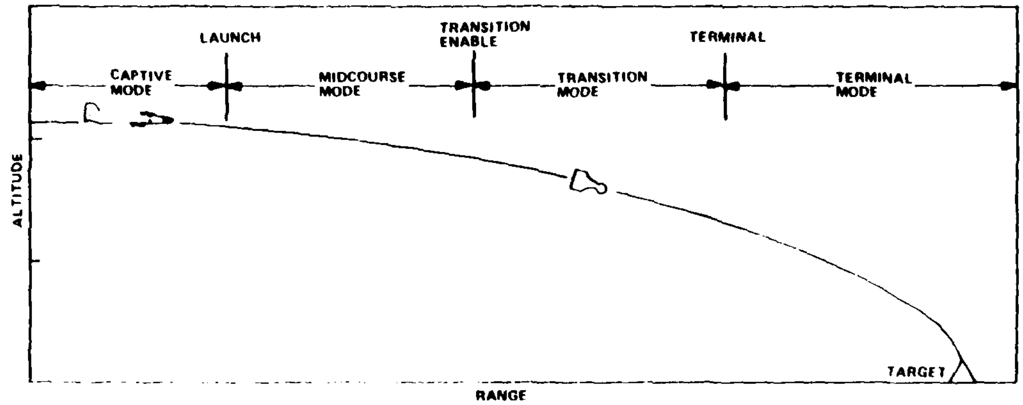
Figure 1   GBU-15 Simulation Configuration

attitude. After 1.75 seconds, full guidance is operable and commands can then be given by the WSO.

3.2.4 The WSO can slew the seeker to look for the target by placing the radar controller in half action and using the hand controller for slewing. Heading change commands can also be given in 1° increments with a toggle switch on the data link control panel. Crosshairs are placed over the target and the WSO can lock on the target at will by pulling the radar hand control trigger to the full action position. The WSO also throws the FUZE ENABLE SWITCH, which begins electrical arming. In the mid-course mode the weapon can be steered only in the yaw plane.

3.2.5 The transition mode is entered when the transition enable switch is turned on or is automatically entered when the seeker look-down angle exceeds 24°. Gate slew is uncoupled from the platform slew (for quicker response to the hand control), and the crosshairs move within the field-of-view while the platform is simultaneously slewed at a linear rate. The weapon can continue to be steered in yaw while pitch is adjusted to maintain the 24° look-down angle. The transition phase should be entered only when the target has been visually acquired and the seeker has been locked on or when the target is being manually tracked.

3.2.6 The terminal phase is initiated manually by setting the terminal switch to Select. If pitch rate reaches 1 degree per second, the system automatically enters the terminal mode (i.e., to prevent operator caused pitch over). The terminal phase is selected only after transition enable or when the seeker has been on or is being



WEAPON CAPTIVE	WEAPON GLIDE WITH HEADING CHANGES	WEAPON GLIDE WITH AUTOMATIC YAW STEERING (AND PITCH OVER AT TRANSITION LINE)	WEAPON PITCH AND YAW STEERING
CREW AC • SET UP WEAPON FOR LAUNCH WSO • SET UP DATA LINK POD • ACQUIRE AND IDENTIFY TARGET OR TARGET AREA	CREW AC • LAUNCH WEAPON • EXECUTE TURN • MAINTAIN POSITION AND LOOK ANGLE RELATIVE TO WEAPON WSO • TRACK TARGET OR TARGET AREA SLEW - LOCK PLATFORM • ADJUST WEAPON HEADING • ARM FUZE (OPTIONAL)	CREW: AC • MAINTAIN POSITION AND LOOK ANGLE RELATIVE TO WEAPON WSO • TRACK TARGET - SLEW - LOCK ON • VERIFY FUZING	CREW: AC • MAINTAIN POSITION AND LOOK ANGLE RELATIVE TO WEAPON WSO • TRACK TARGET - SLEW/UPDATE - RELOCK WEAPON OR - STEER TO IMPACT

REFERENCE GBU-15(V) 4/B AIRCREW WEAPON DELIVERY PROCEDURES PACKAGE, TF 4E 34 1-15-100 (TEST), 28 MAY 1976.

Figure 2 GBU-15 Mission Profile

TABLE 2

WSO Operations after Bomb Release and Aircraft Turn

WSO FUNCTION	RESULTING ACTION
VIDEO - VERIFY GOOD RECEPTION	IF THE VIDEO IS LOST OR DEGRADED BY SNOW, THE AIRCRAFT SHOULD BE ABRUPTLY ROLLED BACK AND FORTH AND THE HEADING SHOULD BE SLIGHTLY ALTERED TO PRODUCE IMPROVEMENT.
RADAR HAND CONTROL - HALF OR FULL ACTION SLEW AS REQUIRED	HALF ACTION IS FOR MANEUVERING. FULL ACTION IS FOR GREATER MANEUVERING.
DL MESSAGE GOOD - OBSERVE	THIS INDICATES THAT COMMAND WAS TRANSMITTED SUCCESSFULLY. THE DL MESSAGE SHOULD BE VERIFIED AFTER EVERY COMMAND.
HDG L/R COMMAND SW - TOGGLE AS REQUIRED.	ONCE TOGGLED, THE GBU MAKES AN APPROXIMATE 1° CHANGE IN HEADING IN EITHER THE LEFT OR RIGHT DIRECTION.
RADAR HAND CONTROL SWITCH - PULL TO FULL ACTION AND THEN RELEASE	THIS PERFORMS TARGET LOCKON.
FUSE/SAFE SWITCH - SET TO FUSE.	THIS ARMS THE WEAPON FUSE. THE BLINKING FUSE ARM LIGHT SHOULD NOW BE OFF*
TRNSN ENABLE SWITCH - SELECT WHEN APPROPRIATE (SHOULD BE ACTIVATED ONLY WHEN THE TARGET HAS BEEN VISUALLY ACQUIRED).	GATE SLEW IS UNCOUPLED FROM PLATFORM SLEW. THE CROSSHAIRS MOVE WITHIN THE FIELD-OF-VIEW WHILE THE PLATFORM IS SIMULTANEOUSLY SLEWED AT A LINEAR RATE. IF THE GATE IS LOCKED ON OR HELD STATIONARY, THE PLATFORM WILL CATCH UP AND THE CROSSHAIRS WILL AGAIN BE CENTERED IN FOV.
A. OBSERVE GATE SLEW	GATE MOVEMENT SHOULD BE COINCIDENT WITH FOV.
B. OBSERVE AUTOMATIC YAW STEERING	NIM SHOULD MOVE TOWARD THE VERTICAL CROSSHAIR.
C. OBSERVE FUSE ARM LIGHT AND VERIFY OFF.	FUSE IS AUTOMATICALLY ARMED IF IT HAS NOT BEEN PREVIOUSLY ARMED WITH THE FUSE/SAFE SWITCH.
D. AUTO PITCH OVER	VERIFY THAT NIM UPWARD MOVEMENT IS ARRESTED AT TRANSITION LINE. IF IT IS NOT STOPPED, SELECT TERM.
TERM SW - SELECT	WEAPON IS STEERED IN BOTH PITCH AND YAW AS DERIVED FROM COMMANDS TO THE SEEKER, WHICH MAY BE EITHER LOCKED-ON OR MANUALLY STEERED.
A. OBSERVE TRANSITION LINE AND NIM (IF SEEKER IS LOCKED ON).	NOTE DISAPPEARANCE.
B. NOTE AUTOMATIC PITCH AND YAW HOMING	WEAPON HEADS DIRECTLY TOWARD GATE.
RADAR HAND CONTROL - USE IN CASE AN AIMPOINT UPDATE IS NEEDED.** RECENTER TARGET IN GATE.	SLEW HALF OR FULL ACTION FOR DESIRED MANEUVERABILITY.
RADAR HAND CONTROL SW - FULL ACTION AND RELEASE.	LOCK ON TARGET.
IMPACT	MANEUVER COMPLETED.

*THE FUZE ARM LIGHT CAME ON AFTER THE BOMB RELEASE BUTTON HAD BEEN DEPRESSED. IT CONFIRMS THAT THE ADL TRANSMISSION IS IN HIGH POWER.

**ADDITIONAL UPDATES MAY BE PERFORMED AS REQUIRED AND AS TIME PERMITS. IF THE DESIRED AIMPOINT IS NOT SUITABLE FOR LOCKON, THE WEAPON MAY BE MANUALLY STEERED TO IMPACT USING THE RADAR HAND CONTROL WITH THE ACTION TRIGGER HELD DEPRESSED. A CLEAR LINE OF SIGHT FOR CONTINUOUS DATA LINK OPERATION MUST BE ASSURED.

manually centered over the target. Terminal select is an irreversible command in which the weapon is guided in both pitch and yaw as derived from commands from the seeker.

3.3 *Data Link Characteristics*

3.3.1 The data link between the GBU-15 and the launch aircraft (or controlling aircraft if different from the launch aircraft) is the critical component control of the GBU-15 to its target. The forward or command link from the aircraft to the GBU-15 is a digital data link that transmits discrete messages containing control information to the weapon. The back link from the weapon to the aircraft transmits TV video and telemetry superimposed on the video. The telemetry, superimposed on the TV video signal, sends the tracking gate (crosshairs), seeker pointing angles (Nose Indicator Marker, NIM), and various discrete data (data link message good, etc.).

3.4 *GBU-15 Controls and Displays*

3.4.1 The GBU-15 controls are situated in both the front cockpit and the rear cockpit of the aircraft. The front cockpit controls are basically used for prelaunch initialization and testing and are not used when the GBU-15 is in flight. The rear cockpit controls are used to control the weapon during its flight. The primary controls of interest for the JRIT studies are shown in Figures 3 and 4.

3.4.2 The display available to the WSO is shown in Figure 5. The scene presented by the TV camera covers the scope face. The symbols generated on the scope face are as shown in Figure 6. The electrical cage mark is present until the platform is initially slewed and it is then removed. The data link "message good" mark appears for 2 seconds following the receipt of a command from the WSO and while the radar hand controller is positioning the tracking gate. The Phase Steerable Array (PSA) bin marker indicates the PSA antenna beam position that is being used. The nose index marker (NIM) represents the weapon body axis with respect to the seeker boresite. The NIM is not displayed in the tracking gate nor is it displayed in the terminal phase when the target is locked on. The transition line marker, which is displayed during the midcourse and transition phases, represents 24° down platform look angle. The crosshairs extend to the display limits for edge tracking and to $\pm$ 15° for area tracking. The crosshairs are centered on the display during the gate slew in the transition and terminal phases. The tracking gate (center of the crosshairs) is a fixed size for edge tracking, and expands about the target for area tracking.

4.0 *GBU-15 SYSTEM SIMULATION*

4.1 *System Simulation Design*

Simulation design is an iterative process involving definition of simulation requirements, parameter and variable definition, derivation of experimental protocol, generation of functional flow diagrams for the simulation, examination of resources potentially applicable to use in the simulation, and synthesis of simulation configurations. The synthesized configurations are then reviewed and modified by iterating the process as required.

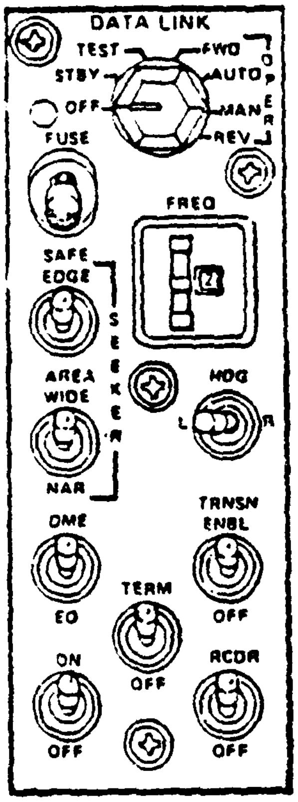


Figure 3 GBU-15 Data Link Controls

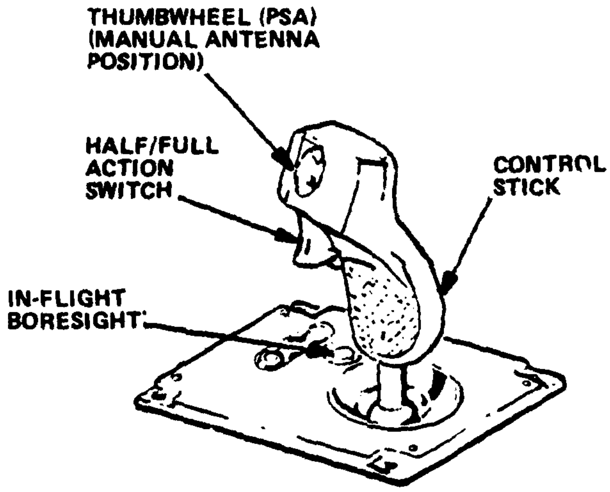


Figure 4 GBU-15 Radar Hand Controller

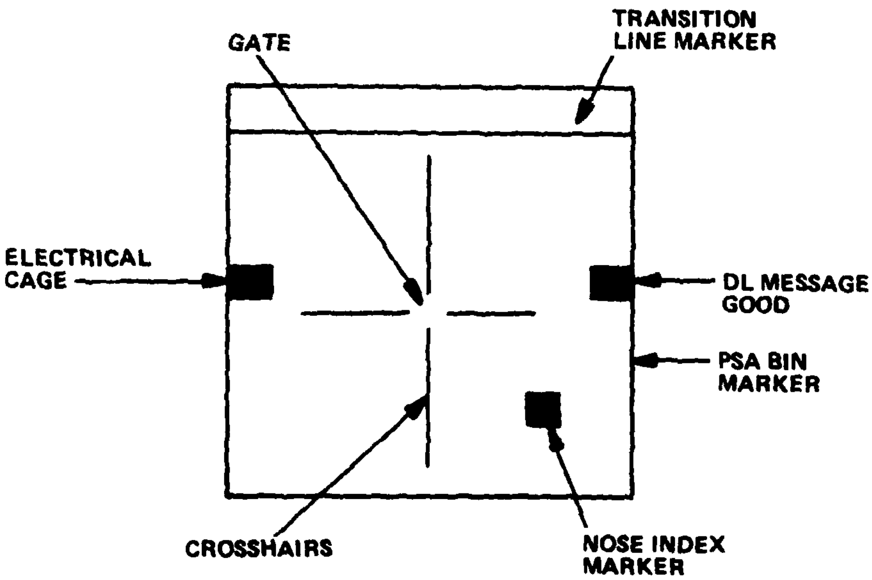


Figure 5 GBU-15 WSO Display

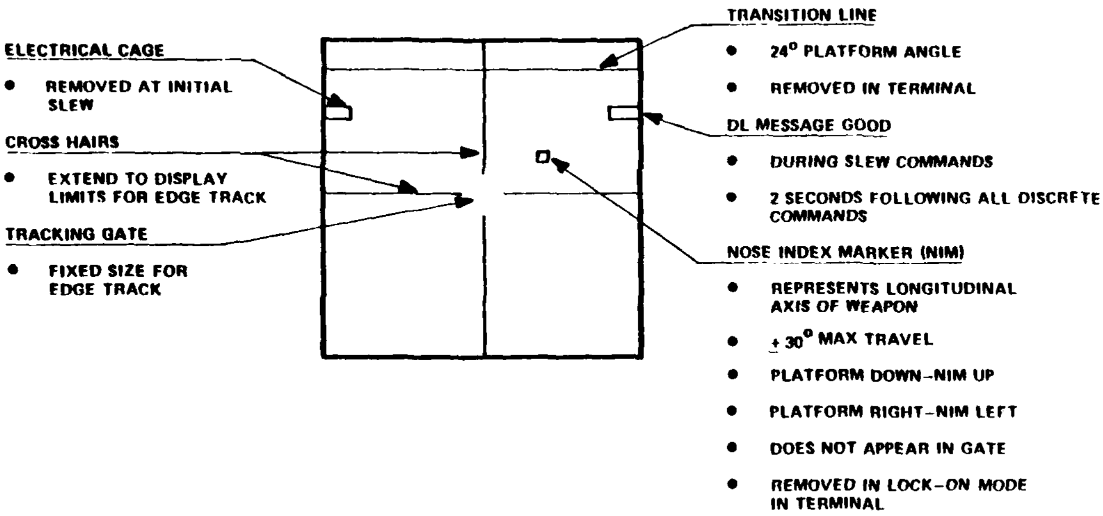


Figure 6 Video Display Symbology

The basic requirements identified for this simulation were:

4.1.1 The simulation should cover the *range of defined* real-world system parameters and variables.

4.1.2 The simulation configuration should make maximum use of available equipments and facilities.

4.1.3 A realistic display must be provided to the operator.

4.1.4 Operator control actions should result in the same effects as obtained in the real-world system.

4.1.5 The operator workload should be realistic. Any scoring or data collection should not involve nonreal-world operator activities.

4.1.6 Simulations should be exactly reproducible to permit side-by-side comparisons to be made of different data link techniques.

4.1.7 Changes in independent variables, parameter values, and initial conditions should be easy to implement.

4.1.8 Real-time computations should be minimized wherever possible. Off-line computations and the use of lookup tables are desirable.

4.1.9 Development risks should be minimized.

4.2 *Functional Flow*

4.2.1 Basic functions that are to be provided in the simulation design include: (a) generation of video signal, (b) generation of jamming signal, (c) generation of jammed video as received at the aircraft, (d) generation of displayed video and symbols, and (e) data collection.

These functions are properly responsive to operator control actions and amenable to changes in parameters or independent variables for any given run.

4.2.2 Operator actions, such as heading-change commands, must pass through the vehicle autopilot transfer function to generate flight commands to apply to the vehicle flyout model. The vehicle flyout model also must be initialized for launch conditions (altitude, velocity, and position). The simulation starts at launch (time equals zero at launch) and the vehicle flyout model outputs the vehicle position (relative to the target) and vehicle attitude (relative to local horizontal and the ground track from launch point to target).

4.3 *GBU-15 Simulation Configuration*

4.3.1 The major elements of the GBU-15 Simulation are discussed briefly. The configuration at AFAMRL is shown schematically in Figure 7. Figure 8 is a schematic of the total configuration across AFAMRL and AFAL.

4.3.2 AFAMRL Flying Spot Scanner (FSS): Was the source of imagery for use in the simulation. The FSS uses aerial oblique photography sectioned into 9" X 9" frames. Figure 9 is a schematic of the general function of the FSS which includes projection of a small raster scan pattern through a positive transparency of each frame of aerial photography and onto a photomultiplier tube. The photographed scene projected by the raster scan is then amplified and sent either to the operator's display (unprocessed video) or over a microwave data link to AFAL for processing. The FSS is coupled to both the GBU-15 vehicle flyout model and a GBU-15 seeker model based on operator inputs. Thus, the size, shape, and position of the raster scan varies in real-time according to the GBU-15 trajectory being flown, as the FSS transitions across the six frames, and operator slew inputs. Figure 10 is a photograph of the FSS film transport including a film pack.

4.3.2.1 FSS targets were obtained via oblique aerial photography collected over straight and level flights at 100,000 ft ground range and approximately 20,000 ft altitude.[3] The targets ranged over a wide variety of types (e.g., power plants, bridges) and locations (e.g., city, suburban, and rural). Photography was collected only under

[3]A more detailed discussion of the selection process, along with a video tape of sample missions, can be made available upon request

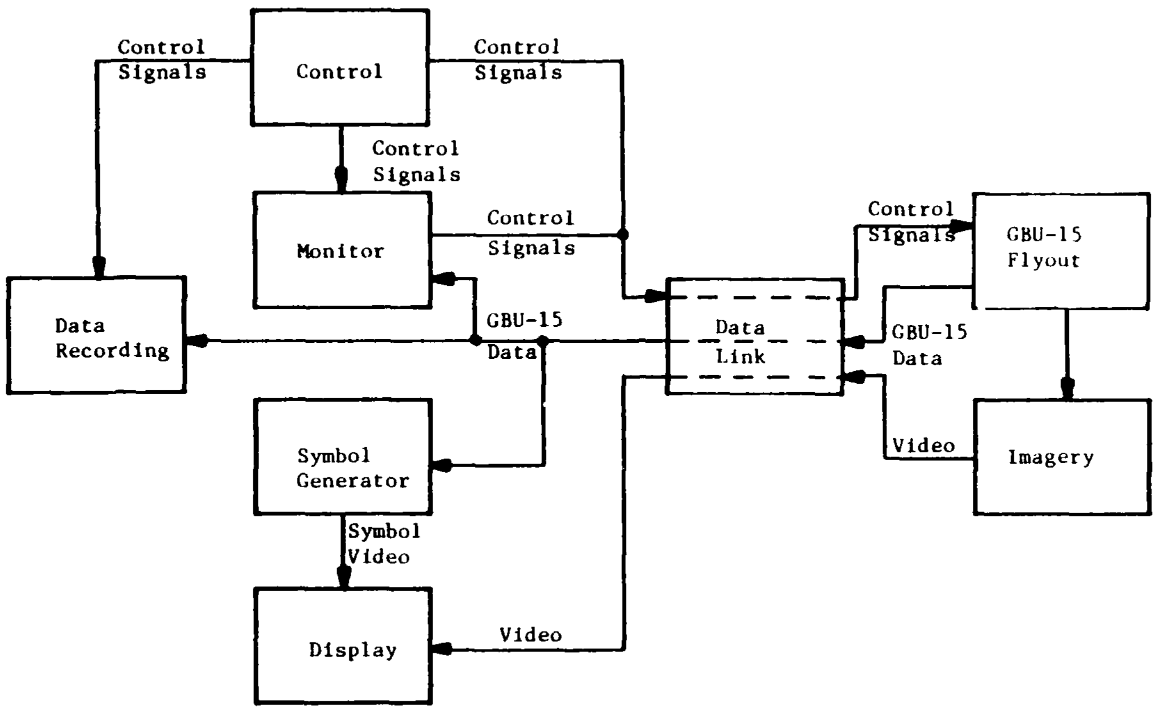


Figure 7 GBU-15 Simulation Functional Flow

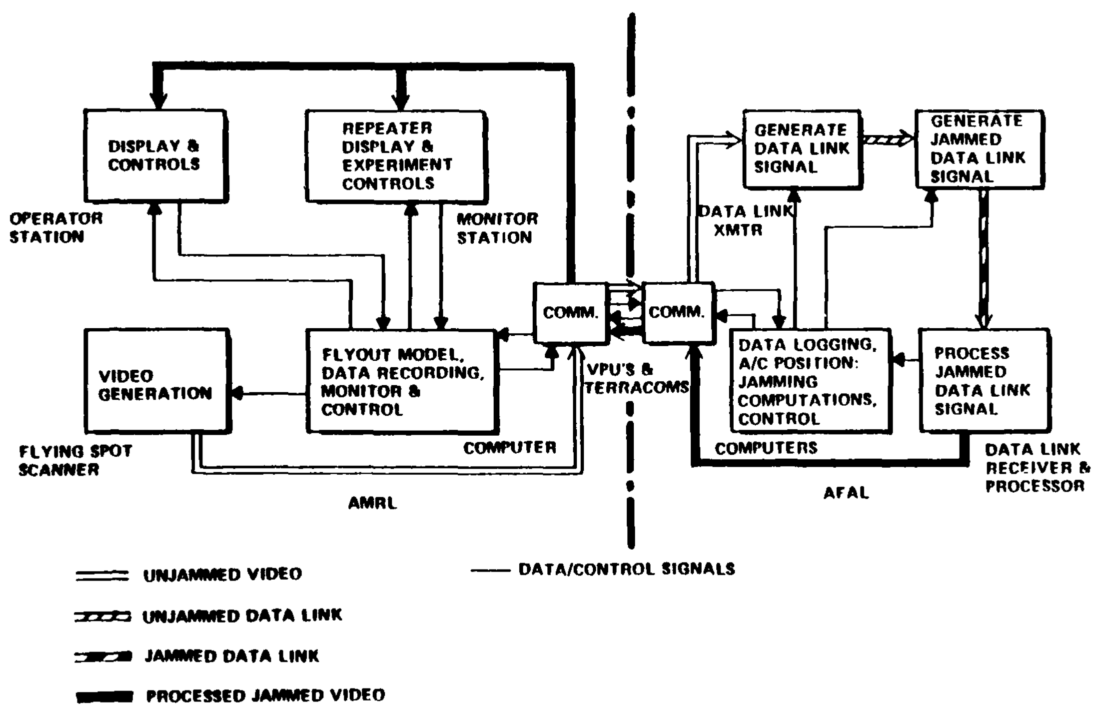


Figure 8 Basic MIL Simulation Block Diagram

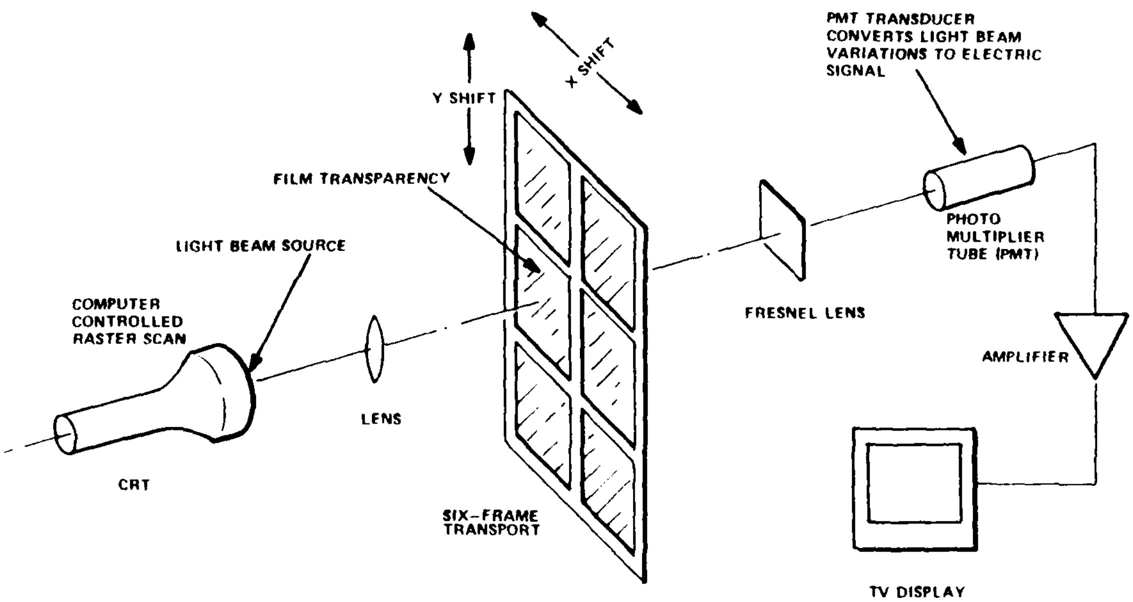


Figure 9 Flying Spot Scanner Using Film Pack Photography

high visibility (clear) weather conditions, high sun, clear ground conditions, and within approximately 100 nautical miles radius of the city of Dayton, OH. Each film pack was made up of six transparencies selected from the total aerial set collected. The selection was made according to a technique developed in AFAMRL such that there would be good transitioning (e.g., no violent change in contrast or aspect angle) from frame to frame during a simulated flight in the FSS. Once a film pack was constructed, it was then calibrated in the FSS such that a given point on one frame would transition to the same point on each of the next five frames. During a simulated flight, there was approximately 1.7 sec. dead time between frame transitions as the result of film transport movement time. During this period, the operator saw what appeared to be in-flight interference on the display. Operators easily adapted to the delay such that it is assumed it had no effect on their performance.

4.3.2.2 Figures 11, 12, 13 and 14 are oblique aerial photographs of two targets: a Freight Depot, Sidney, OH, and Industrial Building, Braysville, IN, respectively. These photographs are positive prints of the first and last (sixth) frame of a film pack. Figures 15 and 16 are photographs of the same targets *after FSS processing,* at a simulated ground range to target of approximately 20,000 ft and an altitude of 11,000 ft. (Note: Figures 15 and 16 were taken from a video monitor and have lost some contrast and sharpness as the result of further processing.) There were 72 target film packs completed by the time the program was terminated. However, film packs had to be constructed as photography became available throughout most of

Figure 10 Flying Spot Scanner with Film Pack of Six Frames of Oblique, Positive Transparent Photography Installed

the program and there was always a desire to limit operator exposure to the same targets. As a result, much of the program was constrained by the number of targets available for each study (see studies below).

4.3.3 Communications Systems Evaluation Laboratory (CSEL) (Image Processing and Jamming): AFAL has the responsibility for providing analysis, synthesis, and modeling of the communications and data link systems. The laboratory provides cost-effective means for dynamic evaluation and comparison of advanced techniques. AFAL uses CSEL equipment and computer hardware along with Processed Imagery Evaluation (PIE) equipment to develop techniques for processing and compressing wideband (video) imagery.

4.3.3.1 Jamming Simulation: The data link attenuation and jamming signal computations are performed on an Avionics Laboratory PDP 11/50 computer. System time data are used to calculate the aircraft position and orientation, and the GBU-15 position and attitude data are used to calculate the antenna gains and relative distances between the weapon and the target. The resulting information is then used to drive the jammer and data link simulation attenuators. The jamming signal and the video imagery data which have been spread spectrum modulated are mixed and then spread spectrum demodulated. After demodulation, the imagery is reconstructed via one of the video compression/reconstruction devices into a conventional video format. The processed video is then retransmitted back to AFAMRL for operator's observance and use while controlling the weapon to its target. (See Goblick et al., 1977, for jamming analyses used in this program.)

4.3.4 TERRACOM Microwave Equipment: Was used to transmit video and other control signals from AFAMRL to AFAL and the processed/jammed video back from AFAL to AFAMRL.

4.3.5 Figures 17, 18, 19 and 20 present function flow diagrams of the real-time computational steps required to merge video, video processing, jamming, and display symbology.

4.3.6 Operator Controls and Display: Figure 21 is a photograph of the GBU-15 simulator's operator station. Figure 22 is a photograph of the B-52 type of GBU-15 display monitor and switch panel. It is assumed that the reader is familiar with the GBU-15 mission at this point to the extent that the pictorials are self-explanatory. Operator controls consist of a panel of switches and a hand controller. The switch panel allows the operator to transition from Midcourse to Transition and to Terminal modes of a mission. The hand controller provides the operator with control over the simulated TV sensor and, via a trigger switch, selection of Slew and Track (auto tracking) modes. Under the Slew mode, vehicle control will *not* be locked to the position of the TV sensor. Under the Track mode, the vehicle attempts to follow the positioning of the TV sensor and would presumably be locked onto the target.

4.3.7 Data Recording and Reduction: Was accomplished on the AFAMRL IBM 370/155. All data parameters were recorded in real time. Table 3 lists these parameters. Data reduction was accomplished after the simulation had been executed. The data reduction merged the real-time data with aircraft trajectory and jamming data (from AFAL) to form a complete data base for each execution of the simulation.

Figure 11 First Frame of Oblique Photography for Target 23A (Circled): Freight Depot, Sidney, Ohio

Figure 12 Sixth Frame of Oblique Photography for Target 23A with Impact Point Circled

Figure 13. First Frame of Oblique Photography for Target "2K" [illegible] Industrial Building, Braysville, Indiana

Figure 14 Sixth Frame of Oblique Photography for Target 14M (Circled)

Figure 15 Sixth Frame for Target 23A after Flying Spot Scanner Processing as Viewed on a Video Display Monitor to the GBU-15 Operators

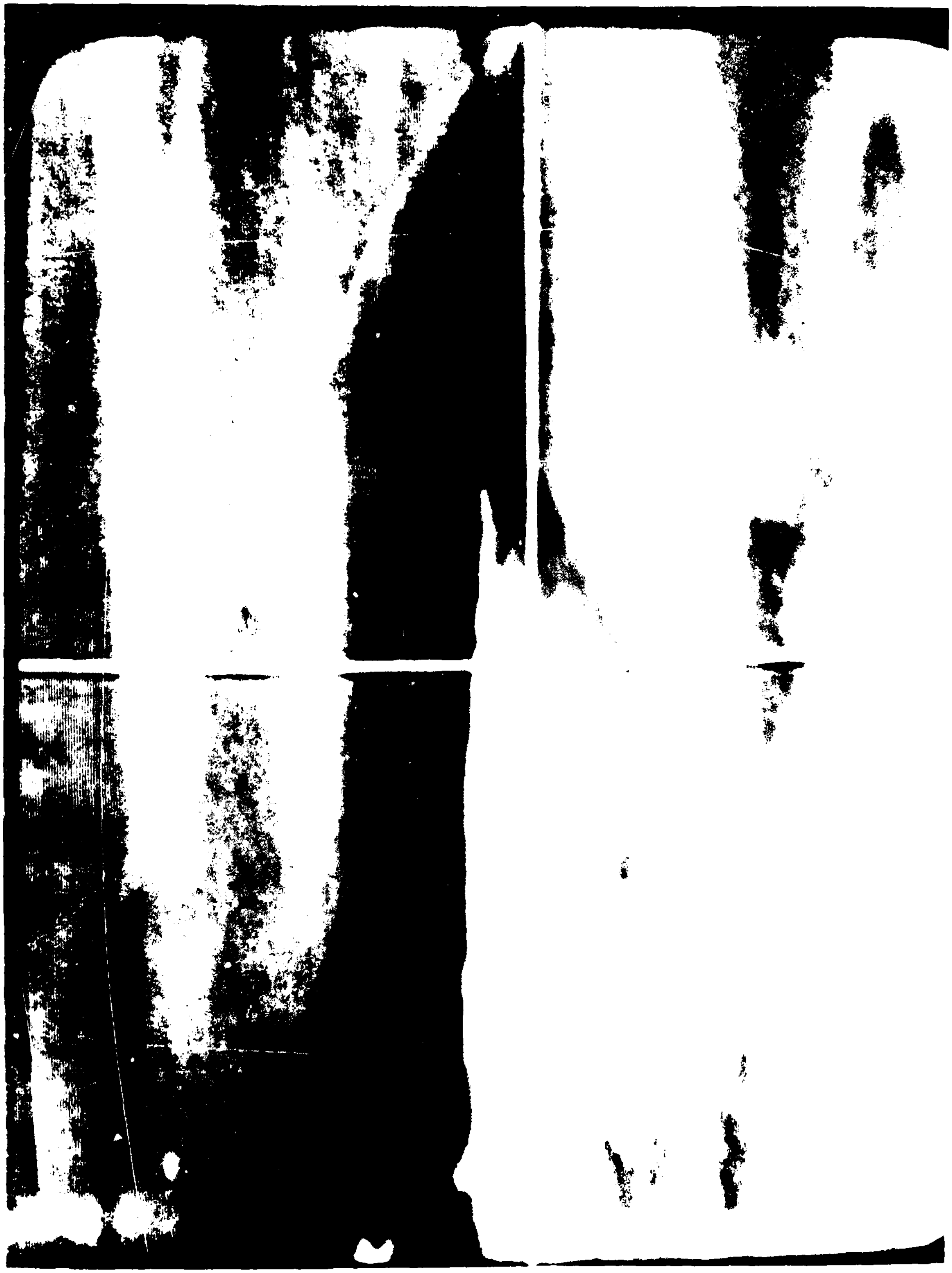


Figure 16 Sixth Frame for Target 14M after Flying Spot Scanner Processing as Viewed on a Video Display Monitor

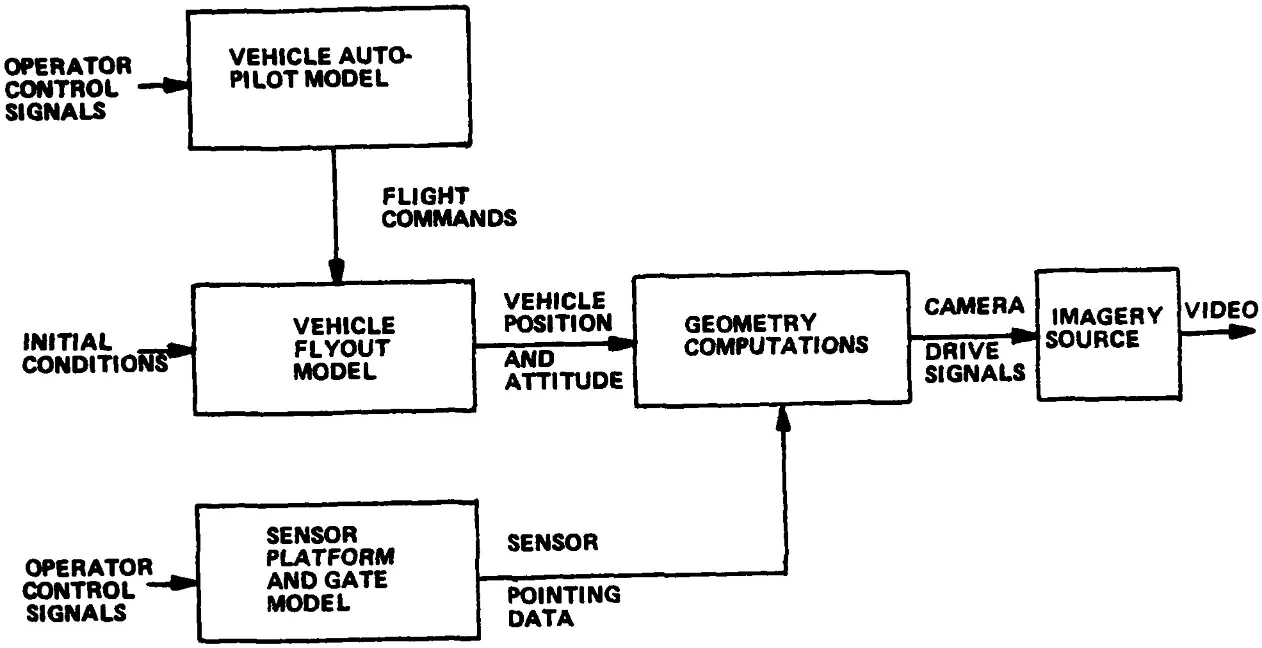


Figure 17 Video Generation

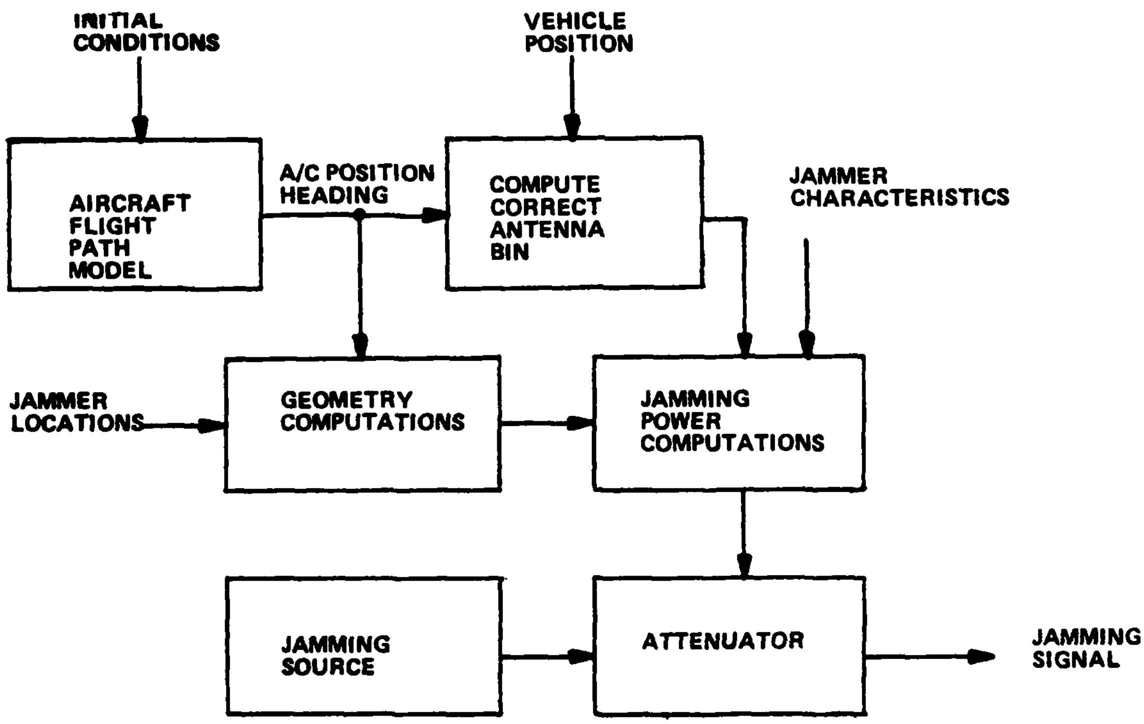


Figure 18 Jamming Signal Generation

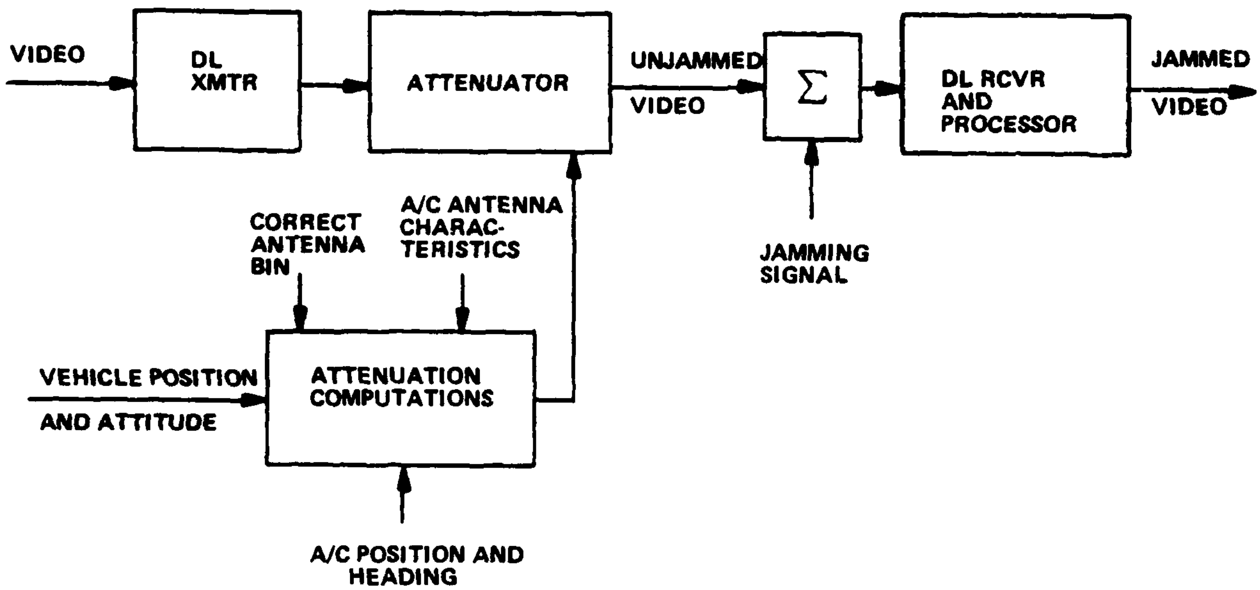


Figure 19 Generation of Jammed Video

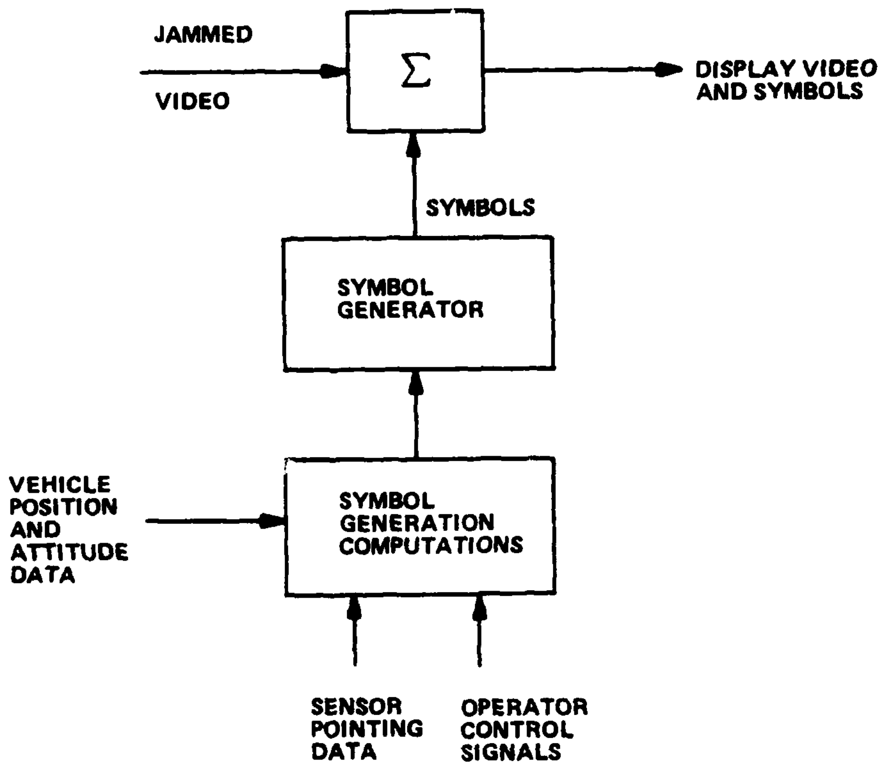


Figure 20 Generation of Display Signals

Figure 21   Operator Work Station in the GBU-15 TV Guided Bomb Simulator

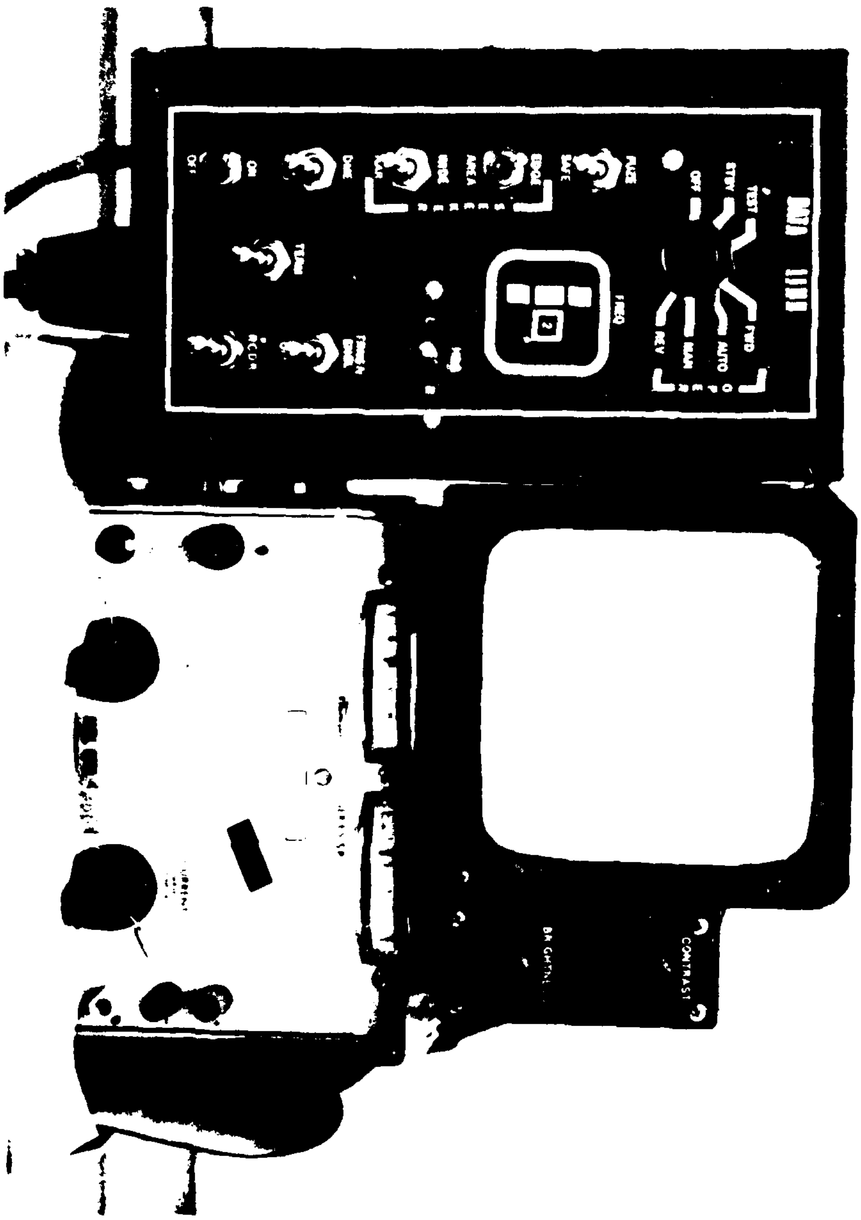


Figure 22 Operator Display (B-52) Monitor and Switch Panel 1 (1-1/4 Scale) in the GBU-15 Guided Bomb Simulator

TABLE 3
Data Recording Output Data

Sequential time ordered file of fixed length records.
Each data item is one 32 bit word

Field	Data Item	Description	Mode*
1	Time	Simulation Time	R
2	X	Downrange Distance from Target	R
3	Y	Crossrange Distance from Target	R
4	Z	Altitude	R
5	Θ	GBU-15 Pitch	R
6	o	GBU-15 Yaw	R
7	Λ	Seeker Platform Pitch	R
8	D	Seeker Platform Yaw	R
9	α	Tracking Gate Pitch	R
10	β	Tracking Gate Yaw	R
11	Mode	GBU-15 Mission Mode	I
12	RHC Action	Half Action/Full Action	I
13	TRANS EN	Transition Enable Switch	I
14	TERM SEL	Terminal Select Switch	I
15	RHC Pitch	Radar Hand Controller Pitch	R
16	RHC Yaw	Radar Hand Controller Yaw	R
17	Launch/Abort	Launch/Abort Command	I
18	Heading	Heading Right/Left Command	I
19	Target Area		I
20	Target Ident.		I
21	Slant Range		R
22	Boresight Error		R

*R is floating point real number format.
I is fixed point integer format.

5.0 *TEST SCENARIO*

Figure 23 presents a drawing of the type of GBU-15 mission scenario "flown" in the GBU-15 simulator testbed for the test evaluations. In these missions, a planar wing GBU-15 was assumed for the flyout model of the simulated vehicle. The simulated vehicle was launched at a ground range to target of 100,000 ft from an altitude of 20,000 ft. The launch vehicle assumed a turn angle of 135° immediately following launch. The general trajectory of the vehicle from launch to target is shown in Figure 24. Actual flight time of a simulated mission was three minutes.

6.0 *OPERATORS AND OPERATOR TRAINING*

Specific operator parameters (e.g., number and sex group assignments, etc.) will be noted with each study. However, initial training and subsequent training for each of the studies remained essentially unchanged throughout the program.

6.1.0 Operators were in their early twenties and had 20/20 vision (corrected and uncorrected). Operator training commenced with an orientation session of instruction

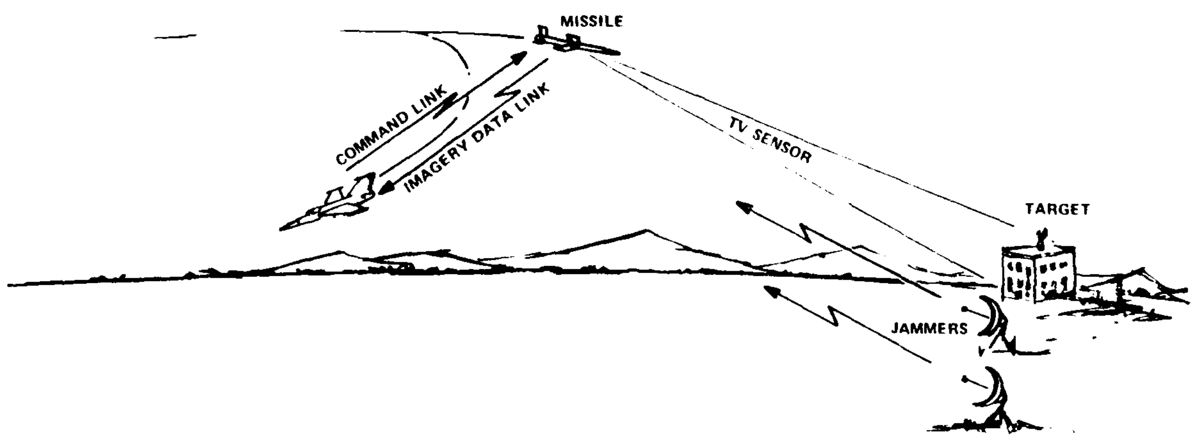


Figure 23 GBU-15 Test Scenario

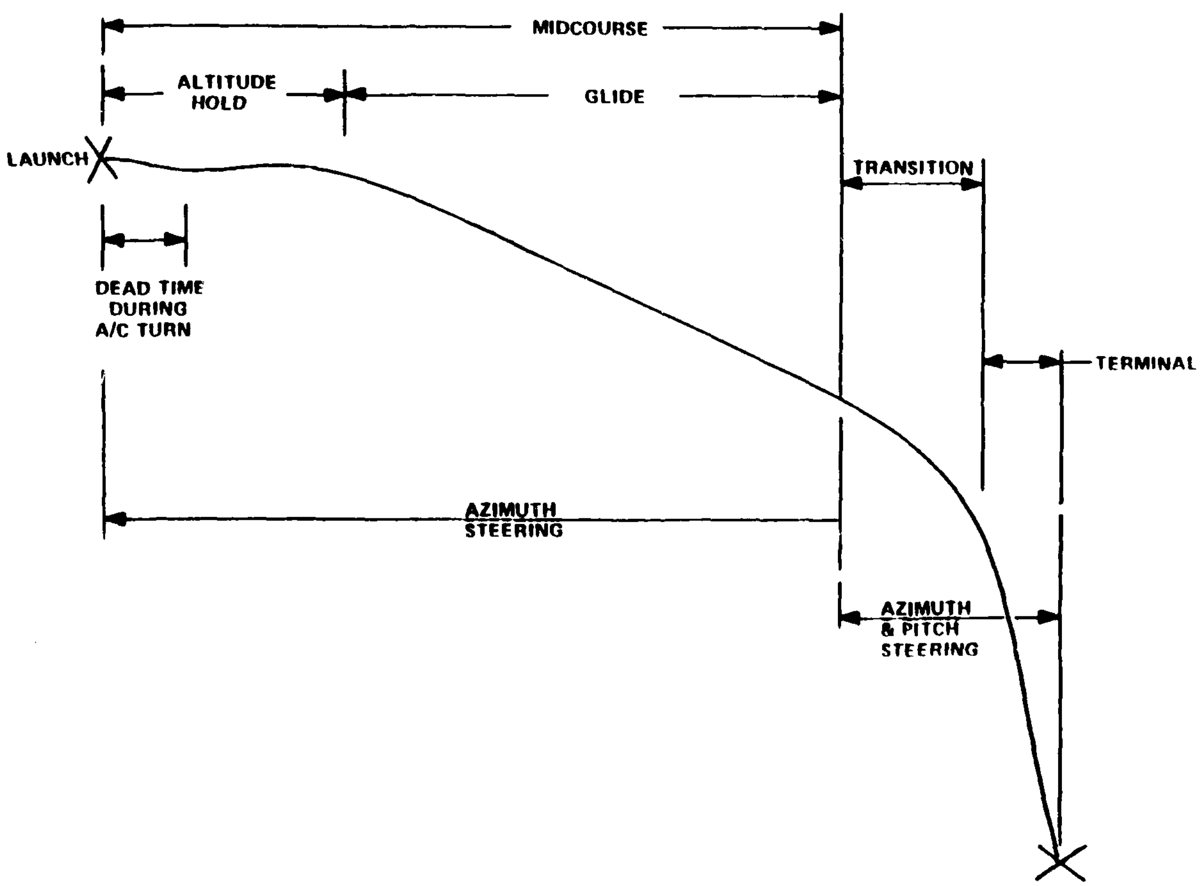


Figure 24 GBU-15 Missile Trajectory

and simulator runs across a single frame of photography. Following the orientation session, each operator completed approximately 30 daily 1/2 hour sessions in the simulator flying training missions. Before each mission, whether training or test, each operator received a briefing packet containing target description, target drawing with precise impact point indicated, and a vertical photograph of the target and target area (see Appendix). Each operator was allowed as much time as desired with the briefing packet before sitting in the simulator. Except for early training runs, the operators were not permitted to have briefing materials in the simulator. The period of time each operator required to study a briefing packet was not measured; however, the time normally ranged from 10 to 15 minutes. Before the start of a given set of evaluation runs, all operators received training under the processing techniques being evaluated.

6.2.0 During the initial training period, each operator was monitored closely by one or more of the investigators and tutored in how to use the briefing material and the display information. For example, the relationship between the crosshairs and NIM during the early period of a mission (without lock-on) can be used to find a target's area since the vehicle is launched on line-of-sight to the target.

6.2.1 Operators were also instructed to lock-on and Transition as soon as they had *identified* the target and to update the aimpoint as often as necessary in order to achieve a high weapon delivery accuracy. Despite these instructions, however, each operator tended to adopt his/her own strategy, e.g. being conservative with regard to first lock-on/Transition by flying the vehicle well past obvious recognition to be sure of the target. For this reason, *final* lock-on and weapon delivery accuracy tended to be the best measures of performance.

7.0 *EVALUATION OF PROCESSING TECHNIQUES*

7.1 Introduction: As is the case with most research programs, the JRIT program tended to be evolutionary in nature. For example, new measures of performance and new experimental procedures were developed or explored as the investigators gained familiarity with the processing techniques, the GBU-15 simulator, the targets and their film packs, etc. Also, as noted earlier, the program was pragmatic; it was desirable to determine the most effective processing techniques to be included in the "flyable" model as quickly as possible. Early in the program, it was not feasible to switch between more than two processors during an experimental session (i.e., bring one or more than two processors on line to the simulator). Furthermore, the jamming simulator had not been completed by the start of the JRIT program and a large complete library of targets was not yet available. For these reasons, a series of three preliminary studies were performed during which a pair of processing techniques were compared across a common set of targets without jamming in each study. This allowed a preliminary determination of the relative effectiveness of the two processors involved within a study but *not across* studies because the target set differed in each study.

Following the three preliminary studies, enough data had become available with respect to the processors and common targets to allow a direct comparison of processing techniques by collecting data on additional common targets. This was

accomplished in the fourth study in which the relative effectiveness of the best four of five processing techniques was measured.

The fourth study was still considered preliminary, however, because a jamming signal had not yet been introduced. This occurred in the fifth study in which the relative effectiveness of the best three of five processors (as determined in the fourth study) was measured after they had been jammed.

7.2 GBU-15 Simulator Accuracy and Effects of Repeated Exposures to Target Film Packs: During the course of the JRIT program, several data collection efforts were performed to determine the accuracy of the simulator and the effects on operator performance of repeated exposures to the same target.

These data collection efforts were performed in order to refine experimental procedures for future studies and to verify the approaches used in the preliminary studies presented herein.

7.2.1 In order to obtain an estimate of the "best accuracy" of the GBU-15 man-in-the-loop (MIL) simulator, a series of twenty passes was made to each of four targets by two experienced operators with unprocessed video after the first study had been completed. It was thought that if operator performance improved as a function of increasing familiarity with a target, mean performance values across the series would tend to asymptote around the minimum obtainable performance value (Table 4 provides the results of these runs). Figure 25 is a plot of Miss Distance at Impact (ft) for *two targets and two operators*. The data from these series of runs verify that operator performance had already achieved an asymptotic mean value because over each series, operators' performance showed no significant improvement or degradation. Furthermore, depending on the target, operators could achieve Miss Distance values of less than 10 feet in the MIL simulator. A good estimate of the best accuracy of the MIL simulator is approximately 10 ft $\pm$ 5 ft.

The lack of an asymptotic performance function across a series of exposures to the same target provides justification for multiple exposures during testing (as long as a reasonable intervening time period has elapsed).

7.2.2 In order to further examine the problem of repeated exposures, ten operators were exposed twice to the same four targets with an intervening period of 7 days between exposures. Table 5 presents the data obtained from the two exposures collapsed over targets and the six of the ten operators with the lowest miss distance values for each target. The elimination of the four poorest performers tended to stablize the data by eliminating "outriders." Table 5 indicates that there was very little change in operator performance from the first pass at the four targets to the second pass. The change in miss distance is less than 6 feet. If there is any indication of familiarization at all, it is in the fact that the operators made slightly fewer updates (reacquisition of lock-on to target) during the second pass. However, fewer updates in combination with the slightly increased range value at final lock-on also may have contributed to the slight decrease in weapon delivery accuracy on the second pass.

The data in Table 5 support the conclusion that two exposures to the same target are acceptable when there is an intervening period of at least 7 days and not more than two exposures.

TABLE 4
Miss Distance at Impact (MDI) (FT) of Twenty Passes to Each of Four Targets by Two Experienced Operators with Unprocessed Video

Operator	Statistic	Target: 1	2	3	4
	Average MDI	13.91	14.31	12.27	11.16
1	Standard Deviation	6.15	10.22	8.21	6.95
	Range (N = 20)	2.58-23.61	3.22-40.92	5.09-40.88	4.24-26.36
	Average MDI	12.92	16.45	18.69	25.74
2	Standard Deviation	8.40	3.61	8.01	20.46
	Range (N = 20)	1.39-36.58	9.00-21.17	6.45-35.91	3.60-102.18

7.2.3 A target library presently exists consisting of 72 targets. Each target in the library is cataloged according to various baseline performance measures obtained for operators using unprocessed imagery and without jamming. According to the measure of Miss Distance at Impact (weapon delivery accuracy) targets vary considerably in their degree of difficulty. The Miss Distance Range = 3.26 ft to 83.80 ft with a Mean Value = 16.32 ft and Standard Deviation = 3.90 ft over 72 targets. The cataloged data were obtained by collapsing over the best three operators of eight original operators who started in the program.

7.3 Study I - 1-DCDP Processing Technique Vs. 2-DCFS Processing Technique. (See Table 1 for definition of techniques.)

7.3.1 Experimental (Test) Design: The 1-DCDP and 2-DCFS processing equipment provided for varying levels of compression [Data Rate in kilobits per second (kbs) transmitted] in terms of the settings on the three variables: Resolution (number of lines), Frame Rate (number of frames per second), and Bits/Pixel (number of bits per picture element).

7.3.2 The variables and the settings (levels) chosen for this evaluation were as follows:

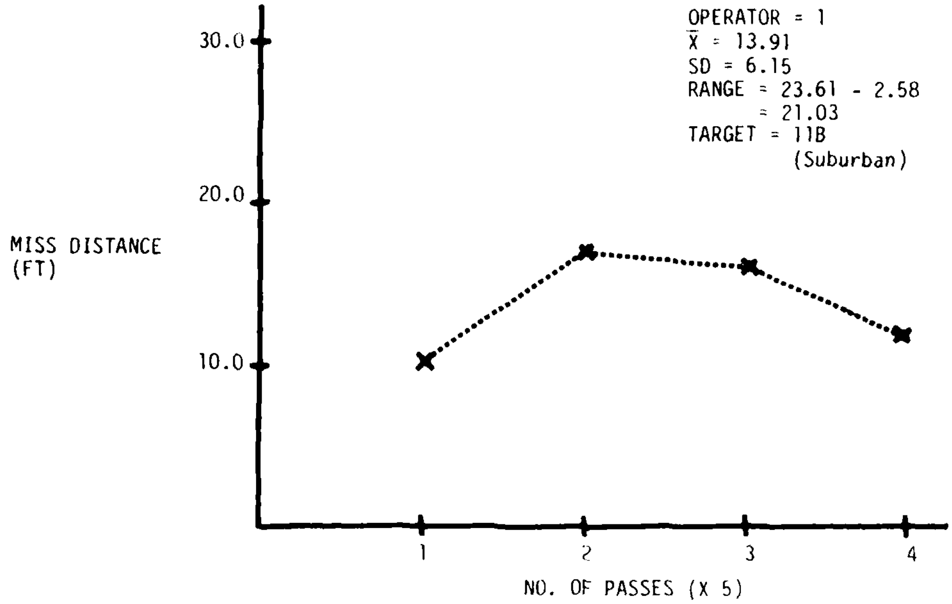
7.3.2.1 Resolution (R) - 128 and 256 lines.

7.3.2.2 Frame Rate (FR) - 1-7/8 and 7.5 frames/sec.

7.3.2.3 Bits/Pixel (BP) - 1 and 2 bits/pixel.

7.3.3 The combination of the levels across variables yields a 2X2X2 factorial experimental design consisting of eight observation vectors (i.e., eight combinations of the three variables under which data were collected). Figures 26, 27, 28 and 29 provide examples of 1-DCDP and 2-DCFS at 600 and 150 kbs processing using the target shown in the unprocessed mode in Figures 14 and 15.[4]

[4]The equipment involved did not allow for a 3-level experimental design (three equidistant settings on each variable) and the 2-level design must assume that performance varies linearly with the compression levels. Also, the DR values do not reflect actual data rates based solely on the settings. Only certain DR values can be employed with the equipment involved. Thus, DR values here represent those obtained after some manipulation (e.g., bit-stuffing) of the original data stream.



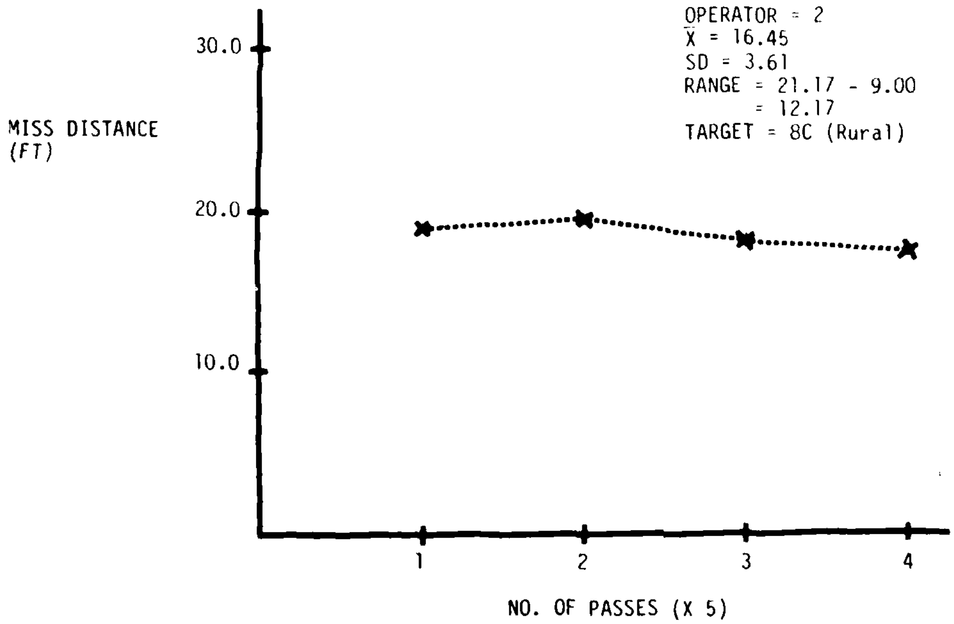


Figure 25 Performance of Two Operators After Twenty Repetitive Passes at the Same Target. Performance Measure is Miss Distance at Impact

TABLE 5
Best Six Operators' Performance On Four Targets Repeated After One Week

Performance Variable	First Pass	Second Pass
Figure of Merit	13.77	19.06
First Lock-On Time (SEC)	15.56	15.46
First Lock-On Range (FT)	92809.25	92825.13
Final Lock-On Time (SEC)	161.33	161.16
Final Lock-On Range (FT)	4778.32	5434.28
Number of Lock-On Updates	33.50	28.96

7.3.4 The observation vectors (R, FR, BP) and the corresponding Data Rates (DR) were:

7.3.4.1 (128, 1-7/8, 1) DR = 75 kbs

7.3.4.2 (128, 7.5, 1) DR = 150 kbs

7.3.4.3 (128, 1-7/8, 2) DR = 75 kbs

7.3.4.4 (128, 7.5, 2) DR = 300 kbs

7.3.4.5 (256, 1-7/8, 1) DR = 150 kbs

7.3.4.6 (256, 7.5, 1) DR = 600 kbs

7.3.4.7 (256, 1-7/8, 2) DR = 300 kbs

7.3.4.8 (256, 7.5, 2) DR = 1200 kbs

7.3.5 Eight operators executed test and baseline GBU-15 simulated missions in two groups of four operators in each group; the 1-DCDP group and the 2-DCFS group. Each group "flew" against two targets under each observation vector (or experimental condition). The two targets per experimental condition and per operator were the same. Targets differed across experimental conditions. Each operator also executed six baseline missions against a set of six targets. Thus, there were 16 evaluation missions and six baseline missions executed by each of the two groups against a total of 22 targets.[5]

7.3.5.1 Each operator was permitted four attempts (passes) at each target. A mission was successful when the operator guided the vehicle to an impact point on the final frame (6th) of photography (i.e., the vehicle had impacted in the vicinity of the target). An aborted mission occurred when an operator had exhausted all four passes without achieving the last frame of photography. The multiple-pass proce-

[5]Time limitations precluded counter-balancing the two groups; however, as will be shown below, the groups were equivalent in performance. Furthermore, time limitations and handling of the film packs precluded the use of larger sets of targets. The liability of a small target set (i.e., two) is that one of the targets might skew a result because it is especially easy or difficult.

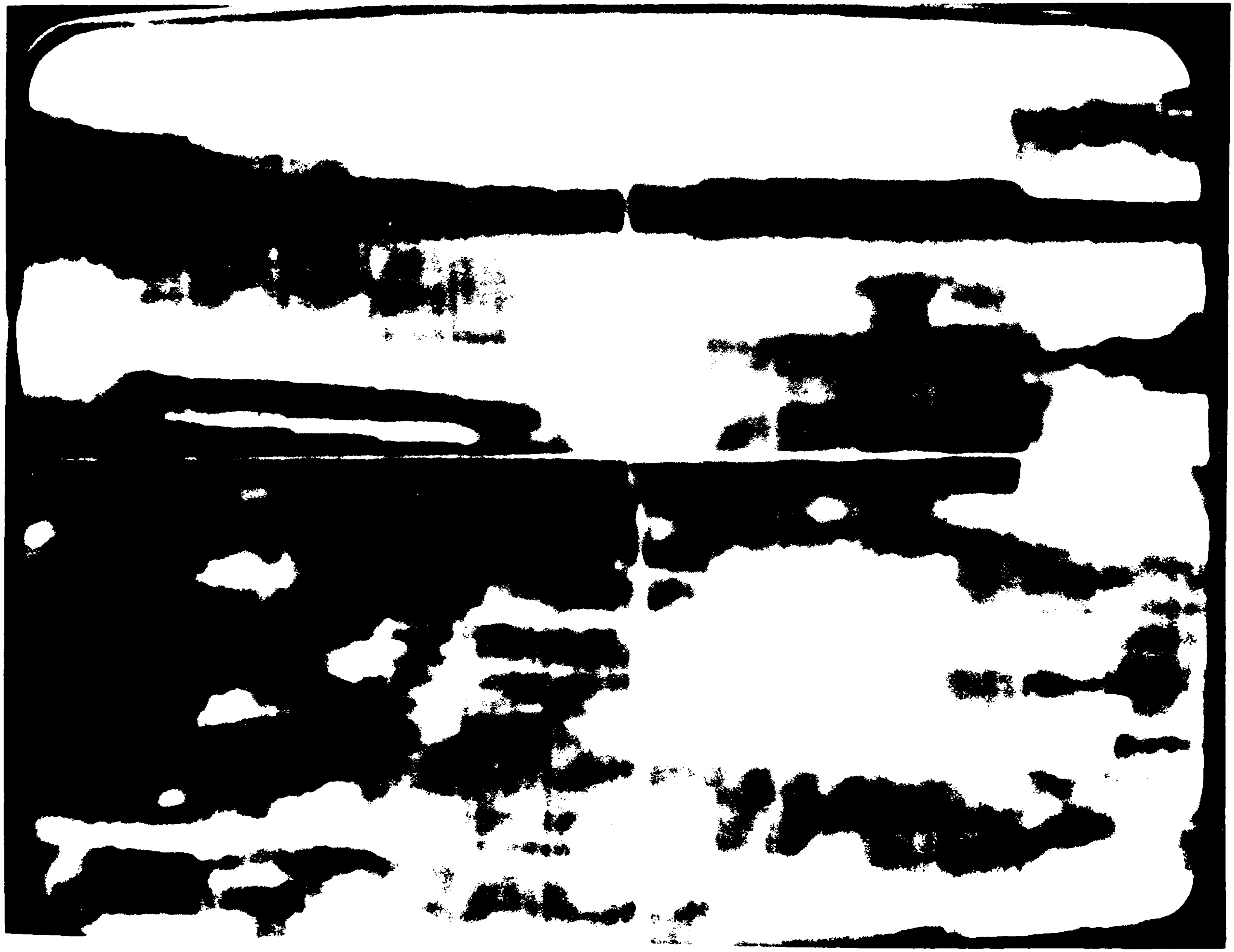


Figure 25 Target 23A Freight Depot Processed at Approximately 20K Ft Ground Range and 11K Ft Altitude Processing Technique was **1-DCDP** with a 600 KBS Transmission Rate

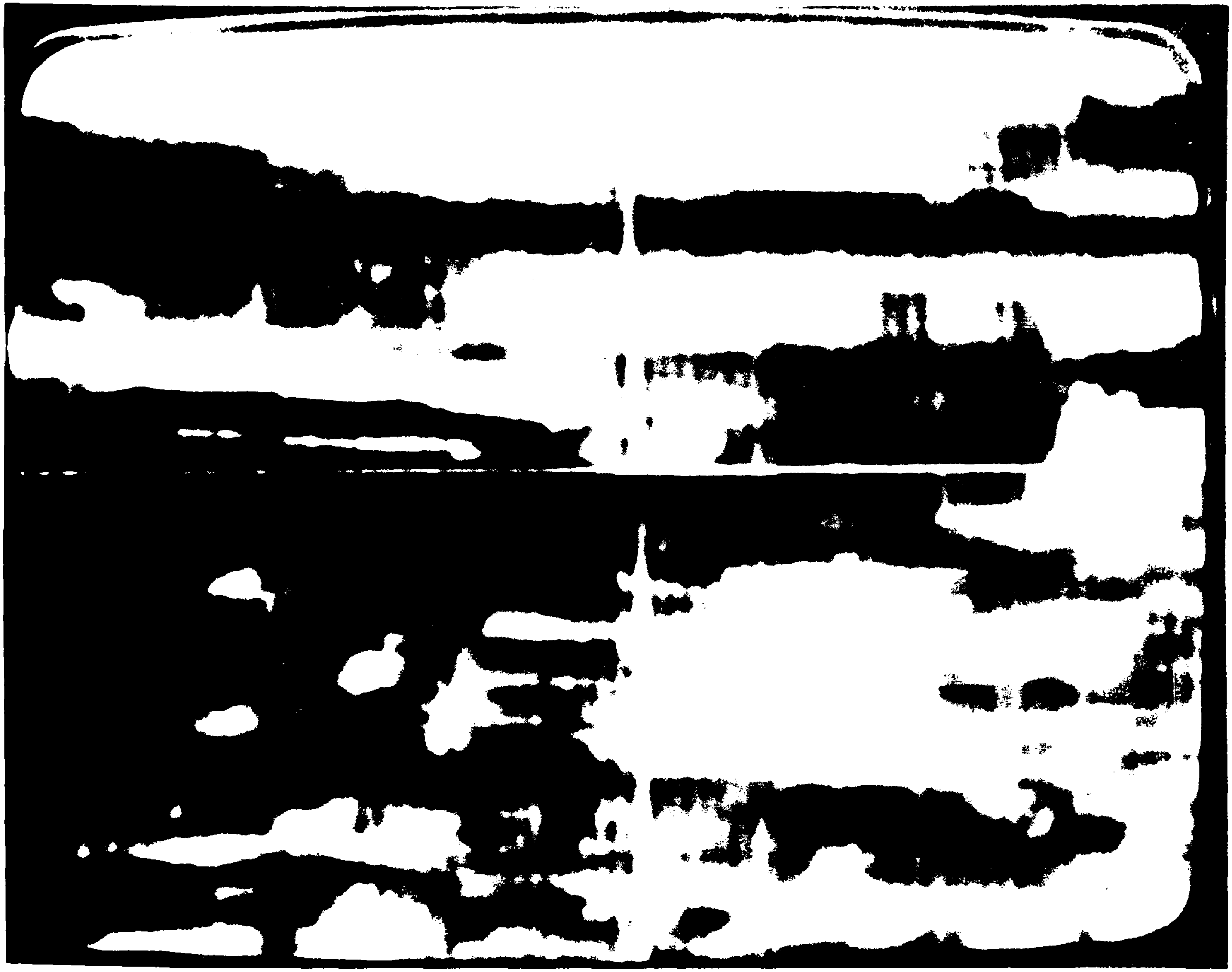


Figure 27 Target 23A Processed at Approximately 20K Ft Ground Range and 11K Ft Altitude
Processing Technique was **1-DCDP** with a 150 KBS Transmission Rate

Figure 28 Target 23A. Processed at Approximately 20K Ft Ground Range and 11K Ft Altitude. Processing Technique was **2-DCFS** with a 600 KBS Transmission Rate

Figure 29 *Target 23A, Processed at Approximately 20K Ft Ground Range and 11K Ft Altitude Processing Technique was* ***2-DCFS*** *with a 150 KBS Transmission Rate*

dure was instituted in order that there would be some assurance that weapon delivery accuracy data would be available. For a given mission, it has been observed that once an operator has found the target area, the mission will terminate successfully.

Thus, "Number of Passes" becomes a measure of an operator's ability to find the target area for a given mission. Furthermore, there is little relation between Number of Passes required to find a target area and weapon delivery accuracy.

7.3.6 *Results and Conclusions of Study I:* The performance variable used in all of the data analyses was Miss Distance at Impact. This variable is simply the RMS distance calculated using lateral and longitudinal error at impact on a flat earth surface. This variable was replaced in the remaining studies by a Figure of Merit (FOM) calculation to be described under Study II (para 7.4.0).

7.3.7 Table 6 presents average Miss Distance data collapsed over two targets and the best three out of four operators per experimental condition. Table 6 also presents the average baseline performance for each group based on the performance of the best three operators within each of the six baseline missions.

7.3.7.1 The data in Table 6 indicate that the 1-DCDP and 2-DCFS groups may be assumed to be equivalent in performance in that the obtained average Miss Distance values are nearly equal (49.87 ft vs. 51.25 ft).

7.3.7.2 Since the two groups may be considered equivalent, Table 6 also indicates that operators performed better with the 1-DCDP compression equipment on line than with that of 2-DCFS. The only exception to this result was for the "worst case" experimental condition with DR = 75 kbs. With this condition removed, performance improved an average of 40.40% when going from the 2-DCFS technique to the 1-DCDP technique.

7.3.7.3 The reversal at R = 128, DR = 75 kbs was not unexpected and was probably the result of the fact that the 1-DCDP processor virtually obliterates all symbology at the R = 128 and low DR conditions (DR $\leq$ 300 kbs). The 2-DCFS processor tends to leave at least some symbology with which to work.

7.3.7.4 The symbology tends to be quite important to operator performance. The crosshair, NIM relationship can be used early in a mission without any imagery at all to keep the operator oriented to the general target area. This occurs because the vehicle is launched on a line-of-sight to the target and therefore, the NIM (early in a mission and before lock-on) is an indicator of the target area. It should be cautioned, however, that a specific test of the usefulness of the symbology with and without processing has not been made. The conclusion has been reached on the basis of observation and some basis in the data.

7.3.8 The abort data further support the conclusion that the 1-DCDP technique outperformed that of 2-DCFS. The total number of aborts (four operators per group) was double that of 1-DCDP under 2-DCFS; 15 aborts under 1-DCDP and 30 aborts under 2-DCFS. Furthermore, no operator ever aborted a mission the maximum four times us-

TABLE 6

Average Miss Distance (Ft) for Best Three Operators and Two Targets Per Experimental Condition Baseline Data are the Averages Across Six Targets for Best Three Operators in Each Group

Baseline: 1-DCDP Group = 49.87/2-DCFS Group = 51.25/Overall = 50.56

Bits/Pixel	Frame Rate	Resolution	Data Rate (kbs)	1-DCDP Compression	2-DCFS Compression
1	1-7/8	128	75	269.05	91.55
		256	150	36.13	130.12
	7.5	128	150	100.09	184.16
		256	600	25.58	30.73
	1-7/8	128	75	80.12	150.98
2		256	300	75.07*	180.69*
	7.5	128	300	62.69	69.16
		256	1200	30.26	45.76

*These miss distances values are probably too high as the result of one of the two targets employed being unusually difficult.

ing 1-DCDP. Under 2-DCFS, however, when an operator aborted a mission, the aborts tended to continue to the maximum of four times. The average number of passes per operator per target was 1.23 under 1-DCDP and 1.41 under 2-DCFS.

7.3.9 An analysis of variance was performed on the *individual* operator and target data for the four operators in each of the two groups. This analysis indicated no significant effects of R, FR, BP, targets or operators. A test performed on the regression equations obtained for each technique showed no significant difference between equations.

7.3.9.1 The analysis did, however, indicate that operator performance was more consistent (i.e., less variable) under the 1-DCDP processor.

7.3.9.2 An examination of the amount of variance contributed by each variable (R, FR, BP) suggested that certain of the variables could be evaluated as more important than others despite the lack of statistical significance. This statement is supported by Table 6 which shows that for the 1-DCDP equipment, it would be best to set the resolution value at maximum, followed by frame rate and then bits/pixel. For the 2-DCFS equipment, the order of resolution and frame rate is reversed.

7.3.10 Figures 30 through 35 are plots of each of two of the variables while holding the third constant. Two observations can be made about these figures.

7.3.10.1 First, performance tends to be more ordered at each of the R = 256, FR = 7.5, and BP = 2 values. There are crossovers at lower values. A check on individual performance values did not provide an explanation.

7.3.10.2 Second, Figure 33 is most interesting in that it shows a reversal in expected performance on the BP variable, i.e. performance improves from BP = 2 to BP = 1. This observation, combined with the fact that performance appears to improve with processing in some cases relative to baseline performance (see Table 6), suggests that,

under certain conditions, processed imagery may actually facilitate performance. There is a basis for this outcome in previous vision research (Ginsburg, 1978; Ginsburg, 1980). The interpretation is that a reduction in R from 512 to 256 and/or a reduction in BP from 2 to 1 tends to filter high-frequency noise from the imagery for the visual system of an operator; thus, facilitating performance. Exactly how, if, and why this happened in this study is still unclear and will undergo further consideration at AFAMRL. The variable, Miss Distance at Impact, is measuring performance *after* detection and identification; and a difference in miss distance numbers is a measure of an operator's ability to achieve (discriminate and guide the vehicle to) the designated impact point accurately.

7.3.11 Based on the above results, the following conclusions can be reached concerning the relative effectiveness of the 1-DCDP and 2-DCFS processing techniques.

7.3.11.1 Data from the baseline missions indicate the two processor groups were equivalent in their performance.

7.3.11.2 Operators performed better and their performance was more consistent when imagery was being processed by the 1-DCDP compression equipment.

7.3.11.3 For the 1-DCDP compression equipment, resolution is the most important variable followed by frame rate and then bits/pixel.

7.3.11.4 For the 2-DCFS compression equipment, frame rate is the most important variable followed by resolution and then bits/pixel.

7.3.11.5 The effects of the resolution, frame rate, and bits/pixel variables were not found to be statistically significant. Also significant effects on performance were not found as the result of target or between operator variability.

7.3.11.6 Although not specifically tested in this study, it is apparent that display symbology should not be processed at data rates of 300 kbs or less with resolution equal to 128 lines.

7.3.11.7 There is an indication that sometimes processing may facilitate performance relative to baseline.

7.4 Study II - 2-DHEFSt Processing Technique Vs. 2-DAC Processing Technique. (See Table 1 for definition of techniques.)

7.4.1 Experimental (Test) Design: *Before starting the evaluation runs for Study II*, the two groups of four operators each from Study I were assigned to each of the two processing techniques, 2-DHEFSt and 2-DAC. Each group then executed an average of twelve training missions under the processing technique to which it had been assigned.

7.4.2 The 2-DHEFSt and 2-DAC processing equipments provide for varying levels of compression (Data Rate in kbs transmitted) in terms of the settings of the three variables: Resolution (number of lines), Frame Rate (number of frames per second), and Bits/Pixel (number of bits per picture element).

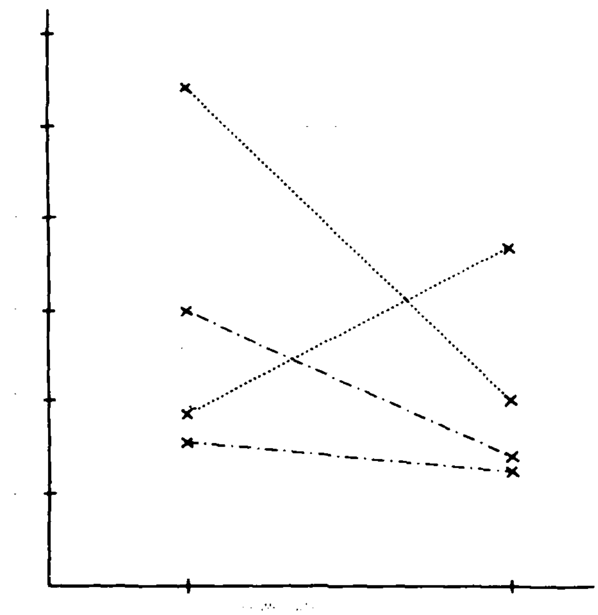


Figure 30 Average Miss Distance for 1-DCDP and 2-DCFS as a Function of Frame Rate and Bits/Pixel Collapsed over Resolution = 128 Lines

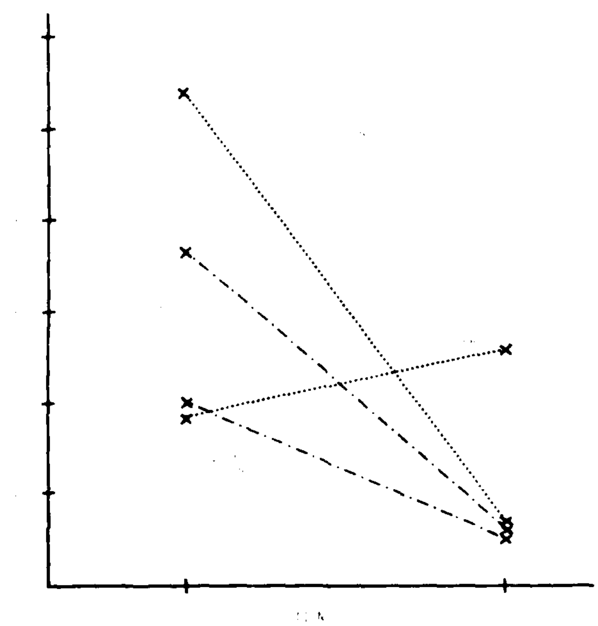


Figure 31 Average Miss Distance for 1-DCDP and 2-DCFS as a Function of Resolution and Frame Rate Collapsed over Bits/Pixel = 1 B/P

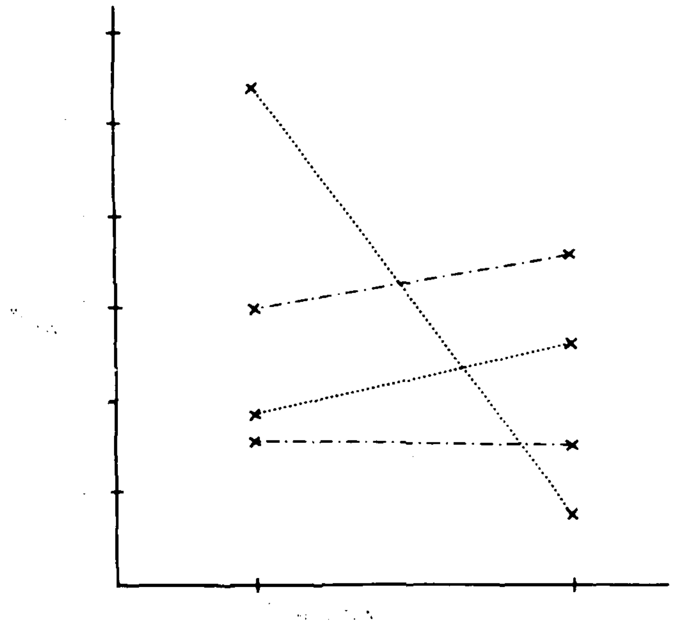


Figure 32   Average Miss Distance for 1-DCDP and 2-DCFS as a Function of Resolution and Bits/Pixel Collapsed over Frame Rate = 1-7/8 FPS

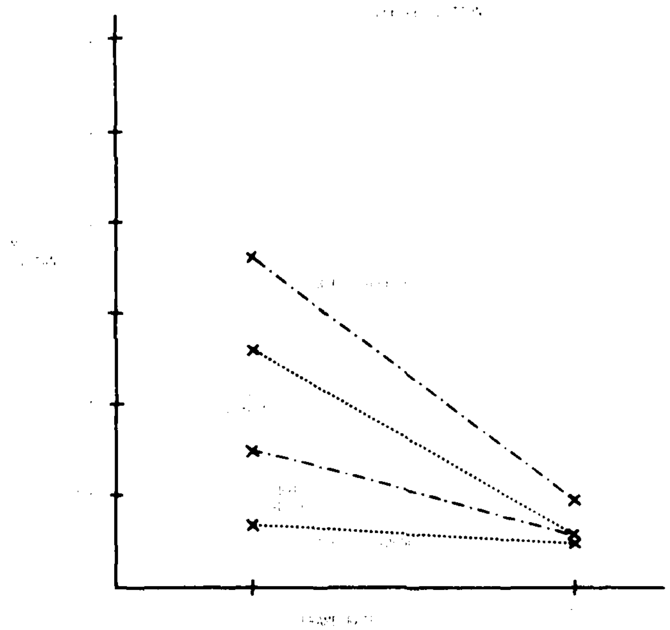


Figure 33   Average Miss Distance for 1-DCDP and 2-DCFS as a Function of Frame Rate and Bits/Pixel Collapsed over Resolution = 256 Lines

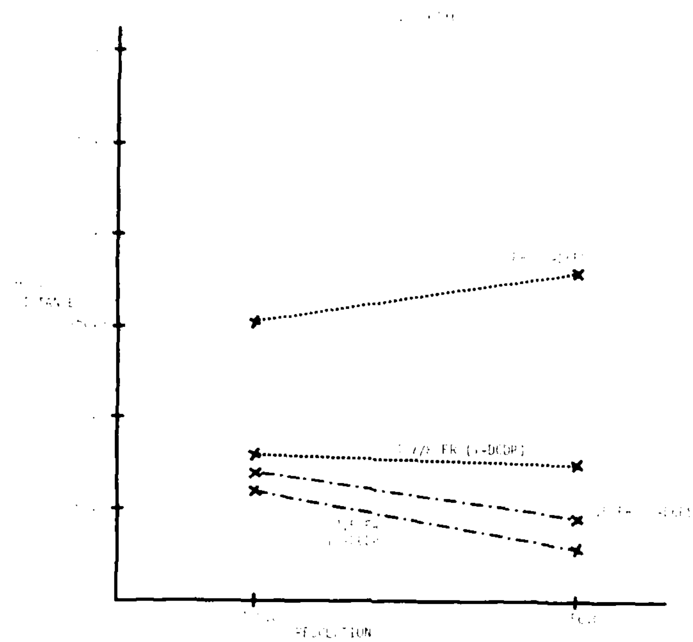


Figure 34 *Average Miss Distance for 1-DCDP and 2-DCFS as a Function of Resolution and Frame Rate Collapsed over Bits/Pixel = 2 B/P*

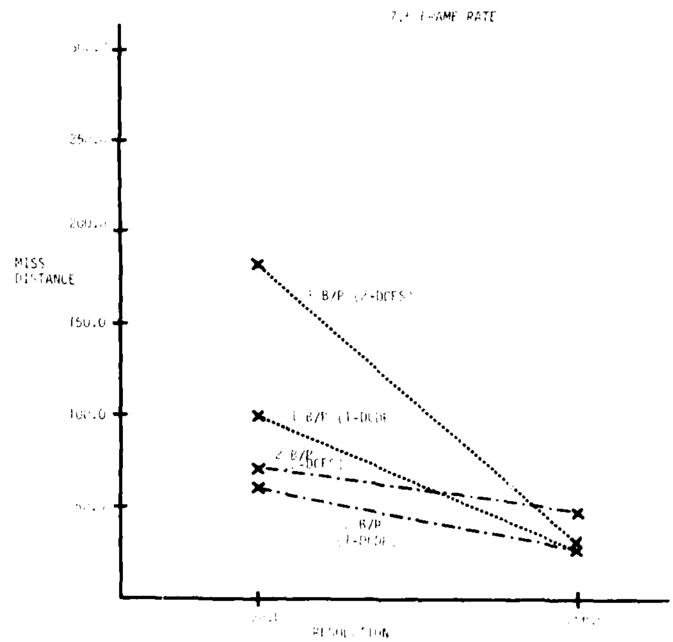


Figure 35 *Average Miss Distance for 1-DCDP and 2-DCFS as a Function of Resolution and Bits/Pixel Collapsed over Frame Rate = 7.5 FPS*

7.4.3 The variables and the settings (levels) chosen for this evaluation were as follows:

7.4.3.1 Resolution (R) - 128 and 256 lines.

7.4.3.2 Frame Rate (FR) - 2 and 7.5 frames/sec.

7.4.3.3 Bits/Pixel (BP) - 1 and 2 bits/pixel for 2-DHEFSt, 1 and 1.5 bits/pixel for 2-DAC.

7.4.4 The combination of the levels across variables yields a 2X2X2 factorial experimental design consisting of eight observation vectors (i.e., eight combinations of the three variables under which data were collected). (See Figures 26 through 29 for samples of processing video from Study I.)

7.4.5 The observation vectors and the corresponding Data Rates (DR) were:[6]

7.4.5.1 (128, 2, 1)	DR = 75 kbs
7.4.5.2 (128, 7.5, 1)	DR = 150 kbs
7.4.5.3 (128, 2, 1.5 or 2)	DR = 75 kbs
7.4.5.4 (128, 7.5, 1.5 or 2)	DR = 300 kbs
7.4.5.5 (256, 2, 1)	DR = 150 kbs
7.4.5.6 (256, 7.5, 1)	DR = 600 kbs
7.4.5.7 (256, 2, 1.5 and 2)	DR = 300 kbs
7.4.5.8 (256, 7.5, 1.5 and 2)	DR = 1200 kbs

7.4.6 Operators executed test and baseline GBU-15 simulated missions in the two groups of four operators each, the 2-DHEFSt group and the 2-DAC group. Each group "flew" against two targets under each observation vector (or experimental condition). The two targets per experimental condition and per operator were the same. Targets differed across experimental conditions and differed from those used in Study I. Each operator also executed baseline missions *against the same* set of targets. Thus, there were 16 evaluation missions and 16 baseline missions executed by the 2-DHEFSt and 2-DAC groups against the total of 32 targets.[7] The justification for exposing an operator to the same target more than once was discussed in para 7.2.

[6]The equipment involved did not allow for a 3-level experimental design (three equidistant settings on each variable) and the 2-level design must assume that performance varies linearly with the compression levels. Also, the DR values do not reflect actual data rates based solely on the settings. Only certain DR values can be employed with the equipment involved. Thus, DR values here represent those obtained after some manipulation of the original data stream (e.g., bit-stuffing)

7.4.6.1 Each operator was permitted four attempts (passes) at each target as in Study I.

7.4.7 Results and Conclusions of Study II: The primary measure of interest in the data analyses was the Figure of Merit (FOM) performance variable. FOM values were obtained for each operator's mission by calculating the product, Number of Passes X Miss Distance Relative to Flight Path (in feet). The Miss Distance Relative to Flight Path variable is calculated in terms of the perpendicular RMS distance from the target to the vehicle's line of flight and does not require a flat earth assumption. Other measures of interest to be presented in tabular form below are (RMS) Miss Distance at Impact (with a flat earth) and the ratio of FOMs obtained under processed and unprocessed imagery for a given mission. The ratio variable tends to remove any differences in baseline performance across the two teams of operators.

7.4.8 Table 7 presents average FOM data collapsed over two targets and the best two out of four operators per experimental condition. Table 7 also presents the average baseline performance for each group based on the performance of the best three operators within each baseline mission. The data for the best two of four operators for each observation vector have been used here because it was only at this level that stable data could be obtained. This is because there were a large number of aborts and rather low accuracy in general under the 2-DAC processor. Tables 8-10 present the data on other measures of interest as noted above. The trend of the data in these tables is the same as in Table 7; however, the absolute values may be of interest.

7.4.8.1 The data in Table 7 indicate that the two processor groups may be assumed to be equivalent in performance in that the obtained FOM values are nearly equal (24.03 vs. 23.25).

7.4.8.2 Since the two groups may be considered equivalent, Table 7 also indicates that operators performed better with the 2-DHEFSt compression equipment on line than with the 2-DAC. The only exceptions to this result were for vectors 4 and 5. Across all conditions, performance was 18.90% better using the 2-DHEFSt processor.

7.4.8.3 Both processors had difficulty maintaining symbology at the 128 resolution and low DR conditons.

7.4.9 The abort data further support the conclusion that the 2-DHEFSt processing technique out-performed the 2-DAC technique. The total number of aborts (four operators per group) was 7 for 2-DHEFSt and 11 aborts under 2-DAC. The average number of passes per operator per target, however, was essentially equivalent under the two processors (1.98 for 2-DHEFSt and 1.99 for 2-DAC).

[7]Time limitations precluded counterbalancing the two groups; however, as will be shown, the groups were equivalent in performance. Furthermore, time limitations and handling of the film packs precluded the use of larger sets of targets. The liability of a smaller target set (i.e., two) is that one of the targets might skew a result because it is especially easy or difficult.

TABLE 7

Average Figure of Merit (FOM*) for Best Two of Four Operators in Each Group and Two Targets Per Experimental Condition (Observation Vector)

Baseline:2-DHEFSt Group = 24.03, 2-DAC Group = 23.25**

Bits/Pixel	Frame Rate	Resolution	Data Rate (kbs)	OBS Vector	FOM 2-DHEFSt Compression	FOM 2-DAC Compression
1	2	128	75	1	56.15	63.91
		256	150	2	58.88	73.35
	7.5	128	150	3	49.01	98.71
		256	600	4	32.96	23.31
	2	128	75	5	118.74	80.45
1.5 (2-DAC)		256	300	6	16.99	37.22
2 (2-DHEFSt)	7.5	128	300	7	43.97	129.10
		256	1200	8	29.15	42.18
			Overall Average FOM		50.73	68.53

*FOM = (Number of Passes) X (Miss Distance Relative to Flight Path) Calculated for Each Operator.

**Based on Best Three Operators of Four and the 16 Test Targets.

TABLE 8

Average Miss Distance Relative to Line of Flight (MDRF) (FT) for Best Two of Four Operators in Each Group and Two Targets Per Experimental Condition (Observation Vector)

Bits/Pixel	Frame Rate	Resolution	Data Rate (kbs)	OBS Vector	MDRF 2-DHEFSt Compression	MDRF 2-DAC Compression
1	2	128	75	1	36.78	51.04
		256	150	2	53.73	60.08
	7.5	128	150	3	37.90	62.19
		256	600	4	27.91	23.31
1.5 (2-DAC)	2	128	75	5	73.82	62.83
2 (2-DHEFSt)		256	300	6	19.51	34.98
	7.5	128	300	7	43.96	84.47
		256	1200	8	27.27	41.40
			Overall Average MDRF		39.80	51.96

TABLE 9

Average Miss Distance at Impact (MDI) (FT) for Best Two of Four Operators in Each Group and Two Targets Per Experimental Condition (Observation Vector)

Bits/Pixel	Frame Rate	Resolution	Data Rate (kbs)	OBS Vector	MDI 2-DHEFSt Compression	MDI 2-DAC Compression
1	2	128	75	1	47.26	63.71
		256	150	2	73.69	73.41
	7.5	128	150	3	41.94	60.11
		256	600	4	36.10	29.74
1.5 (2-DAC)	2	128	75	5	86.71	75.98
2 (2-DHEFSt)		256	300	6	19.51	34.98
	7.5	128	300	7	46.83	95.11
		256	1200	8	35.54	53.00
			Overall Average MDI		48.45	60.76

Table 10

Average Ratio Processor FOM: Baseline FOM (RPB) for Best Two of Four Operators in Each Group and Two Targets Per Experimental Condition (Observation Vector)*

Bits/Pixel	Frame Rate	Resolution	Data Rate (kbs)	OBS Vector	RPB 2-DHEFSt Compression	RPB 2-DAC Compression
1	2	128	75	1	3.03	4.46
		256	150	2	3.60	3.50
	7.5	128	150	3	1.55	2.78
		256	600	4	2.56	4.25
1.5 (2-DAC)	2	128	75	5	1.78	1.27
2 (2-DHEFSt)		256	300	6	0.89	2.01
	7.5	128	300	7	9.20	9.32
		256	1200	8	1.57	2.12
			Overall Average RPB		3.02	3.71

*Baseline FOM Obtained From Best Three Operators.

7.4.10 An analysis of variance was performed on the *individual* operator and target data for the four operators in each of the two groups. This analysis indicated no significant effects of R, FR, or BP. A test performed on the regression equations obtained for each processor showed no significant difference between equations.

7.4.10.1 The analysis did, however, indicate that operator performance was slightly more consistent (i.e., less variable) under the 2-DHEFSt processing technique.

7.4.10.2 An examination of the amount of variance contributed by each variable (R, FR, BP) suggested that certain of the variables could be evaluated as more important than others despite the lack of statistical significance. In general, it would be best to set the resolution value at maximum followed by frame rate and then bits/pixel for *both* processors.

7.4.11 Based on the above results, the following conclusions can be reached concerning the effectiveness of the 2-DHEFSt and 2-DAC processing techniques.

7.4.11.1 Data from the baseline missions indicate the two processor groups were equivalent in their performance.

7.4.11.2 Operators performed better and their performance was slightly more consistent when imagery was being processed by the 2-DHEFSt compression equipment.

7.4.11.3 For both pieces of compression equipment, resolution is the most important variable followed by frame rate and then bits/pixel.

7.4.11.4 The effects of the resolution, frame rate, and bits/pixel variables were not found to be statistically significant.

7.4.11.5 Although not specifically tested in this study, it is apparent that display symbology should not be processed at data rates of 300 kbs or less with resolution equal to 128 lines.

7.5 Study III - 2-DHEFSt Processing Technique Vs. 2-DHIFSt Processing Technique. (See Table 1 for definition of techniques.)

7.5.1 Experimental (Test) Design: Before starting the evaluation runs for Study III, the two groups of four operators from Studies I and II were assigned to each of the two processing techniques, 2-DHEFSt and 2-DHIFSt. At that point, each group executed an average of twelve training missions under the processing technique to which it had been assigned. The group of four operators assigned to the 2-DHEFSt technique was not the same group assigned to this technique in Study II.

7.5.2 The 2-DHEFSt and 2-DHIFSt processing equipment provide for varying levels of compression (Data Rate in kbs transmitted) in terms of the settings on the three variables: Resolution (number of lines), Frame Rate (number of frames per second), and Bits/Pixel (number of bits per picture element).

7.5.3 The variables and the settings (levels) chosen for this evaluation were as follows:

7.5.3.1 Resolution (R) - 128 and 256 lines.

7.5.3.2 Frame Rate (FR) - 1-7/8 and 7.5 frames/sec for 2-DHIFSt, and 2 and 7.5 frames/sec for 2-DHEFSt.

7.5.3.3 Bits/Pixel (BP) - 1 and 2 bits/pixel.

7.5.4 The combination of the levels across variables yields a 2X2X2 factorial experimental design consisting of eight observation vectors (i.e., eight combinations of the three variables under which data were collected). (Figures 14 and 15 are samples of video processing from Study I.)

7.5.5 The observation vectors and the corresponding Data Rates (DR) were:[9]

7.5.5.1 (128, 1-7/8 or 2, 1)	DR = 75 kbs
7.5.5.2 (128, 7.5, 1)	DR = 150 kbs
7.5.5.3 (128, 1-7/8 or 2, 2)	DR = 75 kbs
7.5.5.4 (128, 7.5, 2)	DR = 300 kbs
7.5.5.5 (256, 1-7/8 or 2, 1)	DR = 150 kbs
7.5.5.6 (256, 7.5, 1)	DR = 600 kbs
7.5.5.7 (256, 1-7/8 or 2, 2)	DR = 300 kbs
7.5.5.8 (256, 7.5, 2)	DR = 1200 kbs

7.5.6 Operators executed test and baseline GBU-15 simulated missions in two groups of four operators each, the 2-DHEFSt group and the 2-DHIFSt group. Each group "flew" against two targets under each observation vector (or experimental condition). The two targets per experimental condition and per operator were the same. Targets differed across experimental conditions. Each operator also executed baseline missions against the same set of targets. Thus, there were 16 evaluation missions and 16 baseline missions executed by the two groups for a total of 32 targets.[10] The justification for exposing an operator to the same target more than once was discussed in para 7.2.

7.5.6.1 Each operator was permitted four attempts (passes) at each target as in the previous studies.

[9]The equipment involved did not allow for a 3-level experimental design (three equidistant settings on each variable) and the 2-level design must assume that performance varies linearly with the compression levels. Also, the DR values do not reflect actual data rates based solely on the settings. Only certain DR values can be employed with the equipment involved. Thus, DR values here represent those obtained after some manipulation of the original data stream (e.g., bit-stuffing)

7.5.7 Results and Conclusions of Study III: The primary measure of interest in the data analyses was the Figure of Merit (FOM) performance variable. FOM values were obtained for each operator's mission by calculating the product, Number of Passes X Miss Distance Relative to Flight Path (in feet). The Miss Distance Relative to Flight Path variable is calculated in terms of the perpendicular RMS distance from the target to the vehicle's line of flight and does not require a flat earth assumption. Other measures of interest to be presented in tabular form below are (RMS) Miss Distance at Impact (with a flat earth) and the ratio of FOMs obtained under processed and unprocessed imagery for a given mission. The ratio variable tends to remove any differences in baseline performance across the two groups of operators.

7.5.8 Table 11 presents average FOM data collapsed over two targets and the best three out of four operators per experimental condition. Table 11 also presents the average baseline performance for each group based on the performance of the best three operators within each baseline mission. Tables 12-14 present the data on other measures of interest as noted above. The trend of the data in these tables is the same as in Table 11; however, the absolute values may be of interest.

7.5.8.1 The data in Table 11 indicate that the two processing groups of operators may be assumed to be equivalent in performance in that the obtained FOM values are nearly equal (22.05 vs. 23.43)

7.5.8.2 Since the two groups may be considered equivalent, Table 11 also indicates that operators performed better with the 2-DHIFSt compression equipment on line than with the 2-DHEFSt technique. The only exception to this result was for vector 1. Across all conditions, performance was 31.80% better using the 2-DHIFSt processor.

7.5.8.3 Both processors had difficulty maintaining symbology at the 128 resolution and low DR conditions.

7.5.9 The abort data further support the conclusion that the 2-DHIFSt technique outperformed that of 2-DHEFSt. The total number of aborts (four operators per group) was 29 for 2-DHEFSt and 18 aborts for 2-DHIFSt. The average number of passes per operator per target, however, was essentially equivalent under the two processors (1.46 for 2-DHEFSt and 1.29 for 2-DHIFSt).

7.5.10 An analysis of variance was performed on the *individual* operator and target data for the four operators in each of the two groups. This analysis indicated no significant effects of R, FR, or BP. A test performed on the regression equations obtained for each technique showed no significant difference between equations.

7.5.10.1 The analysis did, however, indicate that operator performance was slightly more consistent (i.e., less variable) under the 2-DHIFSt processing equipment.

[10] Time limitations precluded counterbalancing the two groups; however, as will be shown below, the groups were equivalent in performance. Furthermore, time limitations and handling of the film packs precluded the use of larger sets of targets The liability of a smaller target set (e.g., two) is that one of the targets might skew a result because it is especially easy or difficult

7.5.10.2 An examination of the amount of variance contributed by each variable (R, FR, BP) suggested that certain of the variables could be evaluated as more important than others despite the lack of statistical significance. In general, it would be best to set the resolution value at maximum followed by frame rate for 2-DHEFSt processor and bits/pixel at maximum followed by frame rate for the 2-DHIFSt processor.

7.5.11 Based on the above results, the following conclusions can be reached concerning the effectivenss of the 2-DHEFSt and 2-DHIFSt processing techniques.

7.5.11.1 Data from the baseline missions indicate the two processor groups were equivalent in their performance.

7.5.11.2 Operators performed better and their performance was slightly more consistent when imagery was being processed by the 2-DHIFSt compression equipment.

7.5.11.3 The effects of the resolution, frame rate, and bits/pixel variables were not found to be statistically significant.

7.5.11.4 Although not specifically tested in this study, it is apparent that display symbology should not be processed at data rates of 300 kbs or less with resolution equal to 128 lines or less.

7.6 Study IV - Direct Evaluation of the 1-DCDP, 2-DCFS, 2-DHIFSt and 2-DHEFSt Processing Techniques. (See Table 1 for definition of processing techniques.)

7.6.1 Purpose of Study IV: To this point in the JRIT program alternative processing techniques had been evaluated by pairwise comparisons in each of three previous studies. No direct comparison of techniques employed in any two different studies has been possible because the target sets across studies differed; and it was not feasible to have more than two processing units available to bring on-line to the simulator at the same time. The purpose of Study IV was to obtain "quick look" evaluation data on four of the most promising of the original five processing techniques across a set of common targets. The fifth technique, 2-DAC was not included in this evaluation because the results of Studies II and III along with earlier observations suggest it will not out-perform any of the other four and there were time limitations.

7.6.2 Experimental (Test) Design: The specific evaluation approach regarding operator training procedures, performance measures, etc., were the same as in the previous three studies with the following exceptions:

7.6.2.1 The four operators tested in the 2-DHIFSt evaluation group and the four operators tested in the 2-DHEFSt group in Study III were retested with the 1-DCDP or 2-DCFS processors on-line to the simulator. The groups were switched to these processors following Study III and a series of baseline missions. The operators were tested on four observation vectors (processor equipment settings) against four targets that had been used in Study III with the same settings on the 2-DHEFSt and 2-DHIFSt processors. Thus, all processors (1-DCDP, 2-DCFS, 2-DHIFSt and

TABLE 11

Average Figure of Merit (FOM)* for Best Three of Four Operators in Each Group and Two Targets per Experimental Condition (Observation Vector)

Baseline: 2-DHEFSt Group = 22.05, 2-DHIFSt Group = 23.43

Bits/Pixel	Frame Rate	Resolution	Data Rate (kbs)	OBS Vector	FOM 2-DHEFSt Compression	FOM 2-DHIFSt Compression
1	2 (2-DHEFSt)	128	75	1	54.20	88.72
	1-7/8 (2-DHIFSt)	256	150	2	181.67	37.02
	7.5	128	150	3	97.24**	155.45**
		256	600	4	57.25	38.50
2	2 (2-DHEFSt)	128	75	5	27.95**	18.23**
	1-7/8 (2-DHIFSt)	256	300	6	62.58	26.97
	7.5	128	300	7	85.24	70.79
		256	1200	8	111.62	26.41
			Overall Average FOM		84.72	57.76

*FOM = (Number of Passes) X (Miss Distance Relative to Flight Path) Calculated for Each Operator.

**Based on one Target Only.

TABLE 12

Average Miss Distance Relative to Line of Flight (MDRF) (FT) for Best Three of Four Operators in Each Group and Two Targets Per Experimental Condition (Observation Vector)

Bits/Pixel	Frame Rate	Resolution	Data Rate (kbs)	OBS Vector	MDRF 2-DHEFSt Compression	MDRF 2-DHIFSt Compression
1	2 (2-DHEFSt)	128	75	1	53.53	61.98
	1-7/8 (2-DHIFSt)	256	150	2	160.29	27.73
	7.5	128	150	3	97.24	106.32
		256	600	4	57.25	38.50
2	2 (2-DHEFSt)	128	75	5	20.43	18.23
	1-7/8 (2-DHIFSt)	256	300	6	50.20	26.97
	7.5	128	300	7	85.24	67.08
		256	1200	8	111.62	25.98
			Overall Average MDRF		79.48	46.60

TABLE 13

Average Miss Distance at Impact (MDI) (FT) for Best Three of Four Operators In Each Group and Two Targets per Experimental Condition (Observation Vector)

Bits/Pixel	Frame Rate	Resolution	Data Rate (kbs)	OBS Vector	MDI 2-DHEFSt Compression	MDI 2-DHIFSt Compression
1	2 (2-DHEFSt)	128	75	1	74.94	97.32
	1-7/8 (2-DHIFSt)	256	150	2	195.10	33.18
	7.5	128	150	3	98.64	113.76
		256	600	4	63.92	43.89
2	2 (2-DHEFSt)	128	75	5	26.90	26.28
	1-7/8 (2-DHIFSt)	256	300	6	68.61	38.20
	7.5	128	300	7	97.99	78.93
		256	1200	8	134.12	80.17
			Overall Average MDI		95.03	63.97

TABLE 14

Average Ratio Processor FOM: Baseline FOM (RPB) for Best Three of four Operators In Each Group and Two Targets per Experimental Condition (Observation Vector)

Bits/Pixel	Frame Rate	Resolution	Data Rate (kbs)	OBS Vector	RPB 2-DHEFSt Compression	RPB 2-DHIFSt Compression
1	2 (2-DHEFSt)	128	75	1	4.33	4.40
	1-7/8 (2-DHIFSt)	256	150	2	8.66	1.23
	7.5	128	150	3	12.55	11.78
		256	600	4	3.39	3.30
2	2 (2-DHEFSt)	128	75	5	2.04	1.13
	1-7/8 (2-DHIFSt)	256	300	6	0.79	1.76
	7.5	128	300	7	2.13	2.94
		256	1200	8	2.28	9.97
			Overall Average RPB		4.52	4.56

2-DHEFSt) produced simulator performance data under otherwise identical conditions including target set.

7.6.2.2 The observation vectors chosen for the four missions were as follows: (1) BP = 1, FR = 7.5, R = 256, DR = 600; (2) BP = 2, FR = 1-7/8, R = 256, DR = 300; (3) BP = 2, FR = 7.5, R = 128, DR = 300; (4) BP = 1, FR = 1-7/8, R = 256, DR = 150, where BP = Bits/Pixel, FR = Frame Rate (fps), R = Resolution, DR = Data Rate (kbs).

7.6.2.3 The four data rates were considered to be an appropriate sample of the data rates of interest. The target set of four was considered to be of sufficient size for a preliminary comparison of the processors.
The reader is reminded that determining how the processors perform in jamming is the real purpose of the JRIT evaluation. Thus, no definite conclusions are possible until the jamming missions have been executed.

7.6.3 Results and Conclusions of Study IV: It is noteworthy to mention that results and conclusions at this point are preliminary, applying only to baseline and processed video *without* jamming. Performance with processed video that is jammed is central to this program; thus, these early analyses merely set the stage for the final efforts with jamming.

7.6.3.1 Table 15 presents the Figure of Merit (FOM = Number of Passes X Miss Distances), data obtained by collapsing across the four observation vectors. The FOM, FOM ratio, and Percentage Change With Respect to the 1-DCDP processor data clearly indicate that performance using the same targets was second best under the 2-DCFS processor. The 2-DCFS processor somewhat degraded performance with respect to performance under 1-DCDP processing and there was substantial degradation under the remaining two processing techniques.

7.6.3.2 The use of collapsed data can be somewhat misleading if the trend of the data is not the same across each individual target. Performance (large or small FOM value) on one of the four targets could distort the collapsed FOM value. In the case of the collapsed data of Table 15, the average of the rank order of each processor within targets was 1-DCDP = 1.25, 2-DCFS = 2.75, 2-DHIFSt = 2.25, and 2-DHEFSt = 3.75. There is a reversal in average rank between 2-DCFS and 2-DHIFSt; and an examination of the data revealed that the 2-DHIFSt and 2-DHEFSt had a relatively large unexplained FOM to one target (BP = 2, FR = 7.5, R = 128, DR = 300). However, the relative positioning of 1-DCDP to 2-DHIFSt and 2-DHEFSt did not change even with this target removed.

7.6.3.3 The important point to be made regarding these results is that more extensive testing is necessary, especially in the presence of jamming, before a final conclusion can be reached.

7.6.4 The only principal difference between the 2-DHIFSt and 2-DHEFSt processors is presumed to be the use of a high quality digital scan converter internal to the 2-DHIFSt processor and a lower quality (PEP-400) scan converter external to the 2-DHEFSt processor. In order to determine the degradation in performance due to the external scan converter, imagery was run through the external scan converter

TABLE 15

Comparison of 1-DCDP/2-DCFS/2-DHIFSt/2-DHEFSt Across Four Common Targets

	1-DCDP	2-DCFS	2-DHIFSt	2-DHEFSt
AVE FOM_P	25.40	30.08	43.07	68 27
AVE FOM_{BL}	32.53	32.04	32.53	32.04
AVE FOM_P/FOM_{BL}	0.78*	0.94*	1.32	2.13
% WRT 1-DCDP Ratio	----	+ 20.51%	+ 69.23%	+ 173.08%

(Based on Miss Distance Relative to Flight Path FOM for Best 3 of 4 Operators/Team. BL = Baseline Unprocessed, P = Processed, Averages are Obtained over 4 Targets One Each at 150, 300, 300, 600 kbs Data Rate.)

*Performance under 1-DCDP and 2-DCFS Processing Actually Enhanced MIL Simulator Performance.

and compared with baseline (unprocessed) performance to the same targets. Four targets were used in this evaluation; two at FR = 7.5 fps and two at FR = 1-7/8 fps.

7.6.4.1 The results of the scan converter runs are presented in Table 16. These results indicate that scan converter processing only slightly degraded performance at FR = 7.5. However, there was a substantial degradation at FR = 1-7/8. A considerable portion of the performance differences between the 2-DHIFSt and 2-DHEFSt processors can be attributed to the use of the external scan converter.

7.7 Major conclusions of the JRIT Program preliminary to the introduction of jamming.

7.7.1 To this point in the JRIT program the following statements can be made about the TV imagery processing techniques evaluated. The next series of tests will introduce electronic jamming into the GBU-15 simulator.

7.7.1.1 Using the symbol .BT. for "Better Than" the five processing techniques can be ordered in terms of operator performance; 1-DCDP .BT. 2-DCFS .BT. 2-DHIFSt .BT. 2-DHEFSt .BT. 2-DAC. (See Table 1 for definition of processing techniques.)

7.7.1.2 Display symbology should not be processed along with its imagery. This is particularly true of data rates less than 600 kbs or resolution values of 128 lines or less.

7.7.1.3 Resolution appears to be the most important factor in determining performance of processed TV imagery. In no case, however, was this statement supported by a statistically significant outcome.

7.7.1.4 Data obtained in Studies I through IV have been internally consistent, except for a few crossovers (data favoring one processing technique nearly as often as another). Trends in data supporting one technique over another were consistent. One can conclude that the GBU-15 MIL simulator is an effective evaluation tool that can provide *relative* (imagery) data link effectiveness data.

TABLE 16
External Scan Converter Data

FR = 7.5, 2 Targets	Baseline	Scan Converter
AVE FOM	82.73	93.30
RATIO	--	1.13
FR = 1-7/8, 2 Targets		
AVE FOM	14.11	29.45
RATIO	--	2.09

(Based on Miss Distance Relative to Flight Path, Best 3 of 4 Operators/ Team Collapsed Over 2 Teams.)

8.0 *IMAGERY PROCESSING UNDER JAMMING*

8.1 Jamming was introduced into the simulator as realistically as possible via a jamming simulator developed by AFAL. The jamming signal was input to a spread spectrum modem which received the TV imagery processor output and provided jam resistant protection. The TV image was then reconstructed with the jamming signal present and sent over the microwave data link (see Figure 8) to the operator's GBU-15 display at AFAMRL.

8.1.1 The jamming simulator assumed a fence configuration located 50 miles behind the target. The power levels of jamming applied in the simulator were calibrated for a 5% bit error rate at a range of 20,000 feet to the target for each of three imagery transmission data rates; 150 kbs, 300 kbs, and 600 kbs. Figures 36 through 41 are examples of jamming of the three processors to be evaluated in Study V. The target and range are the same as in Figures 14 and 15. Note the increase in jamming interference from 150 kbs to 600 kbs or as the bandwidth is increased.

8.2 Study V - Relative effectiveness of the 2-DHIFSt, 1-DCDP, and 2-DCFS processing techniques in the presence of jamming. (See Table 1 for definition of processing techniques.)

8.2.1 Experimental (Test) Design: Procedures in Study V were the same as those of Studies I through IV with the following changes:

8.2.1.1 The number of operators was increased from eight to ten. The two additional operators had received adequate training and had participated in Studies III and IV but their data were not used in the analyses.

8.2.1.2 Operators executed seven training missions with jamming and processing before starting Study V. The training was terminated when, in the judgment of the investigators and the individual operators, performance of the operators had adapted satisfactorily to the presence of the jamming signal.

8.2.1.3 Operators were permitted two passes at a target instead of the four allowed

in Studies I through IV. This was done because previous data indicated that operators exceeding two passes tended to abort. The result of using two passes was a large savings in time with no impact on the data.

8.2.2 Each of the ten operators executed missions under three processing techniques (2-DHIFSt, 1-DCDP, and 2-DCFS) against a target set of three per each of three observation vectors (processor equipment settings). The vectors were chosen because of specific interest and available time. They were as follows:

8.2.2.1 BP = 1, FR = 1-7/8, R = 256, DR = 150 kbs.

8.2.2.2 BP = 2, FR = 1-7/8, R = 256, DR = 300 kbs.

8.2.2.3 BP = 1, FR = 7.5, R = 256, DR = 600 kbs.

8.2.3 According to this paradigm, targets (three) were common within each observation vector across operators but *not across* vectors. Thus, a comparison among the three processors could be made only *within* each vector. It was thought that this would be appropriate within the time allowed since previous relative effectiveness data had tended to be consistent at the data rates chosen here. (At the time of Study V, it was known that the JRIT program would be terminated at least temporarily and a deadline on obtaining jamming data had to be imposed.)

8.2.4 Also, according to this paradigm, operators were exposed to the same target *within each vector* three times; once for each processor. In order to minimize the effects of repeated exposures, the intervening time between each exposure was 7 days - the justification for this approach was discussed in para 7.2. In addition, the data (presented below) were examined and indicated no advantage to a particular processing technique as the result of order of target exposure.

8.3 Results and Conclusions of Study V: Table 17 presents the data collapsed across three targets/vectors and all ten operators. Table 17 contains a variety of performance measures most of which were not analyzed in previous studies for two reasons. First, the software data analysis routine was evolving along with the preliminary studies and these measures were not being obtained. Second, the range, time, and update (reacquisition of lock-on) data were not considered important until a jamming signal was present.

8.3.1 With jamming, however, these measures could be important because the early effects of jamming were visible in the imagery at long ground ranges to target (i.e., 70K to 60K ft) and could influence first and subsequent lock-on performance. Furthermore, final lock-on performance could also be influenced because in the final seconds of a mission, during pitch over, the effects of jamming were lessened as the result of a change in antenna configuration, an operator who was working effectively with a processed/jammed image might get in a last second accuracy adjustment.

8.3.2 In Table 17 the measures of most interest are Figure of Merit (FOM), Final Lock-On Range (FLOR), and Number of (Lock-on) Updates (NUPS). There appears

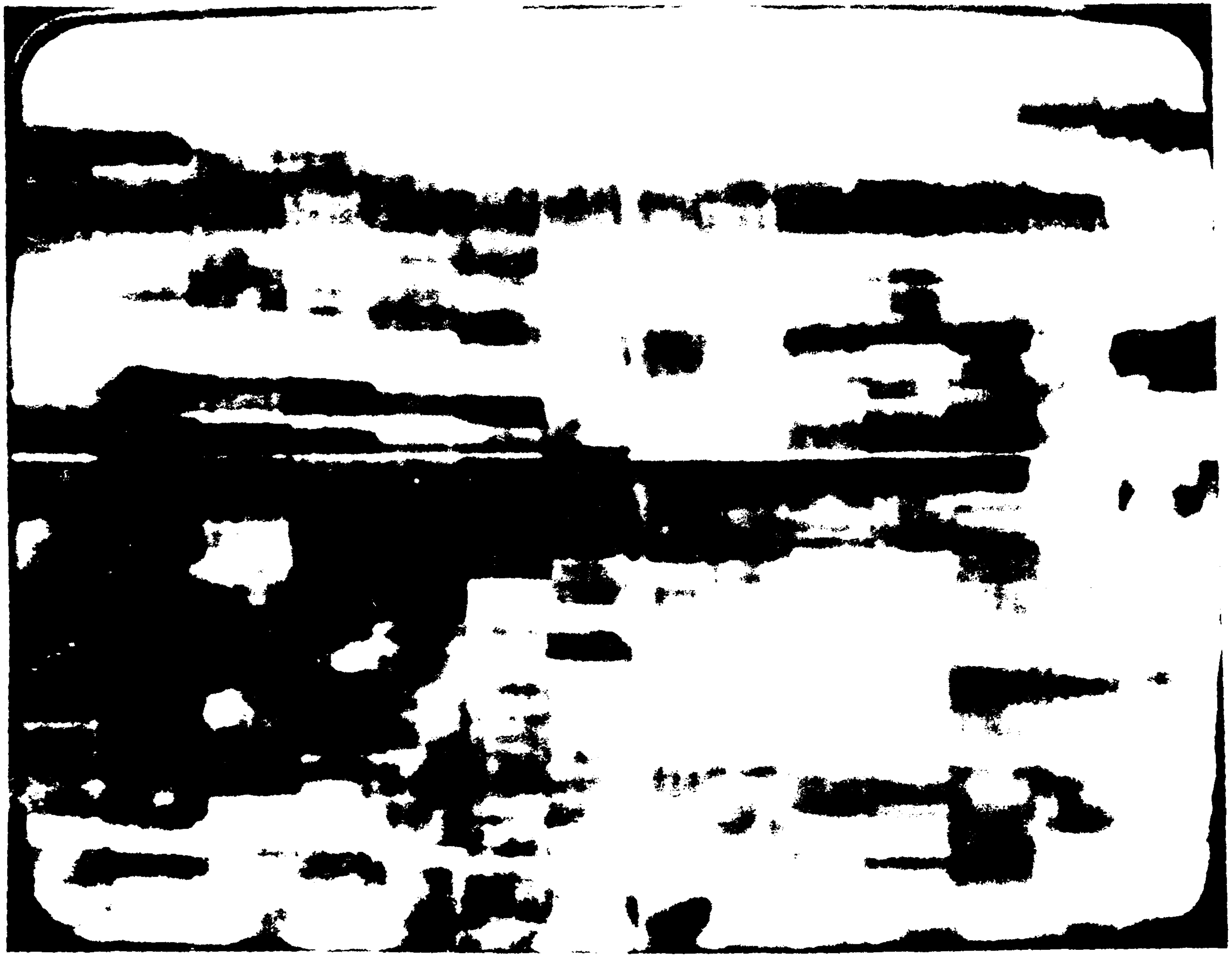


Figure [illegible] Target 23A Freight Depot Processed and Jammed at Approximately 20K Ft Ground Range and 11K Ft Altitude Processing was 1-DCDP with a 600 KBS Transmission Rate

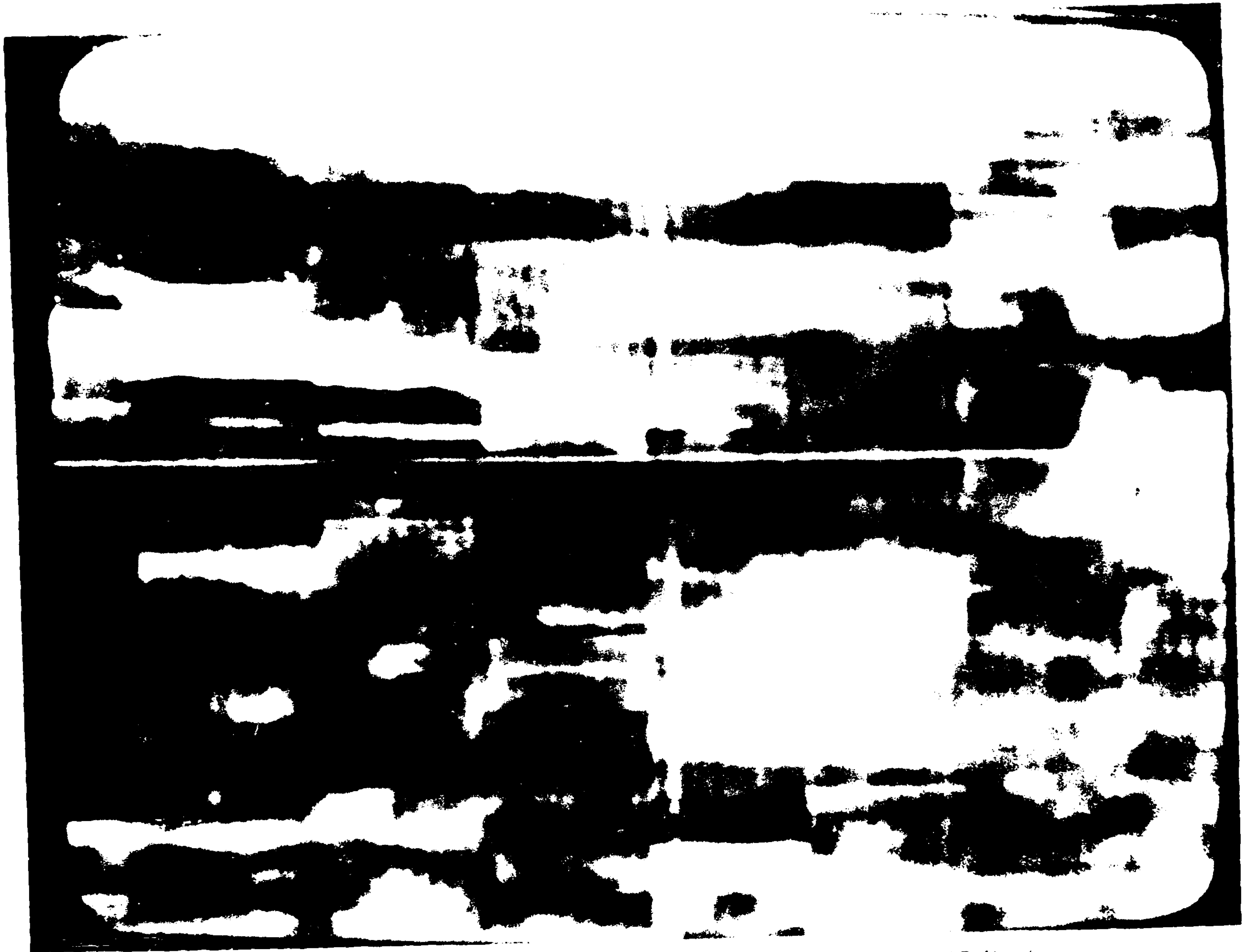


Figure 37 Target 23A. Processed and Jammed at Approximately 20K Ft Ground Range and 11K Ft Altitude Processing Technique was **1-DCDP** with a 150 KBS Transmission Rate

Figure 38 Target 23A, Processed and Jammed at Approximately 20K Ft Ground Range and 11K Ft Altitude Processing Technique was **2-DCFS** with a 600 KBS Transmission Rate

*Figure 39   Target 23A, Processed and Jammed at Approximately 20K Ft Ground Range and 11K Ft Altitude. Processing Technique was **2-DCFS** with a 150 KBS Transmission Rate*

Figure 40. Target 23A. Processed and Jammed at Approximately 20K Ft Ground Range and 11K Ft Altitude
Processing Technique was **2-DHIFSt** with a 600 KBS Transmission Rate

Figure 41 Target 23A Processed and Jamming at Approximately 20K Ft Ground Range and 11K Ft Altitude Processing Technique was **2-DHIFSt** [illegible] KBS Transmission Rate

TABLE 17

Operator Performance in The Presence of Jamming Each of Three Processors. Data Are Averages Across Three Targets and Ten Operators. Targets Differed *Only* Across Data Rates

		Performance Variable						
Data Rate	Processor	FOM	MDRF	LOT	LOR	FLOT	FLOR	NUPS
150 (1, 1-7/8, 256)	2-DHIFSt	123.02	122.04	24.90	87247.44	153.89	10097.27	24.17
	1-DCDP	82.22	76.74	30.83	83680.69	144.99	15986.28	18.93
	2-DCFS	51.71	51.71	30.19	84027.69	157.96	7904.70	22.57
300 (2, 1-7/8, 256)	2-DHIFSt	326.41	203.13	24.52	87593.69	153.07	11234.96	23.47
	1-DCDP	818.15	452.60	34.38	81522.88	139.35	19488.36	17.55
	2-DCFS	80.13	78.93	27.68	85636.06	158.19	7868.60	27.04
600 (1, 7.5, 256)	2-DHIFSt	109.43	76.96	32.00	83023.50	158.95	7176.58	27.77
	1-DCDP	109.49	79.38	27.10	85862.94	158.12	7634.83	25.63
	2-DCFS	58.68	57.38	28.91	84906.56	160.76	5547.41	34.93

FOM - Figure of Merit

MDRF - Miss Dist. Rel. to Flight Path

LOT - Lock-On Time (First)

LOR - Lock-On Range (First)

FLOT - Final Lock-On Time

FLOR - Final Lock-On Range

NUPS -Number of Updates

to be no substantial difference among processing techniques in the case of First Lock-on Range values where jamming effects were minimal and time values are directly correlated with range values.

8.3.2.1 In terms of the FOM, FLOR, and NUPS measures the 2-DCFS processing technique clearly has an advantage over the 1-DCDP and 2-DHIFSt processing techniques. Under the 2-DCFS processor, operators had substantially lower FOM values (i.e., delivered the weapon more accurately), were able to maintain weapon control longer (i.e., smaller FLOR values), and generally make a greater number of accuracy adjustments (i.e., a higher number of updates).

8.3.2.2 Assessing the relative effectiveness of the 1-DCDP and 2-DHIFSt techniques is more difficult. In terms of FLOR and NUPS values, the 2-DHIFSt technique is more effective. However, there is a reversal in terms of FOM for the 150 DR vector and they are virtually equivalent for the 600 DR vector. The GBU-15 simulator lacked what has turned out to be two important parameters; these are a wind drift bias on vehicle trajectory and a loss of lock-on bias. The vehicle was assumed to be unaffected by wind and gust, and once lock-on was established only the operator could break it off and re-establish it. Initially these parameters were thought to be ones which could be delayed for implementation. However, after observing operators performance and the visible effects of jamming, the JRIT investigators are convinced that the 2-DHIFSt technique would have out-performed 1-DCDP processing technique if the wind drift/lock-on bias parameters had been included. The reason for this statement can be seen by comparing Figures 37, 39 and 41. In Figure 37, the image has been nearly obliterated at 20K ft ground range relative to that of Figures 39 and 41. (Note: Operators become very experienced with this imagery and distinctions can be expected to be far greater for them than for the reader.)

Thus, an operator locking-on accurately just before total image obliteration under 1-DCDP processing and *without weapon drift* might be able to achieve comparable accuracy with respect to another processing technique. Table 17 supports this statement particularly in the case of the 600 DR vector in which operators achieved final lock-on values approximately 5000 feet further from the target under 1-DCDP than 2-DHIFSt while achieving equivalent weapon delivery accuracy. Any one or both of the wind drift/lock-on bias parameters could have severely thrown the vehicle off course over 5000 feet.

8.3.2.3 The relatively large FOM and MDRF values obtained for the 300 DR vector are presently unexplained. An examination of operator performance to the individual targets within this vector did not indicate that one target skewed the data. However, it is possible that the three targets chosen for this vector were inherently more difficult for reasons unknown because targets were matched in terms of cataloged baseline performance. Another possible explanation might be in terms of the spatial frequency hypothesis discussed in para 7.3.10.2 since a major difference in the 300 DR vector was that its BP value was set at 2 bits/pixel while the other two vectors were set at 1 bit/pixel. It will be recalled that in Study I, occasions were found in which processing had actually enhanced operator performance. (The relative effectiveness of processing with jamming versus processing versus baseline was not determined because the targets were not common with respect to the vectors of this

TABLE 18

Operator Performance in The Presence of Jamming Each of Three Processors. Data Are Averages Across Three Targets and Best Six Operators. Targets Differed *Only* Across Data Rates

		Performance Variable						
Data Rate	Processor	FOM	MDRF	LOT	LOR	FLOT	FLOR	NUPS
150 (1, 1-7/8, 256)	2-DHIFSt	28.45	27.69	25.31	86992.25	160.33	5999.07	25.50
	1-DCDP	30.51	30.51	26.71	86152.56	150.64	12166.79	19.44
	2-DCFS	31.04	31.04	22.36	88751.50	157.89	7648.12	26.83
300 (2, 1-7/8, 256)	2-DHIFSt	22.35	21.25	25.89	86729.13	158.45	7874.40	23.78
	1-DCDP	69.16	60.97	35.08	81088.00	144.56	16372.45	19.72
	2-DCFS	25.38	24.71	25.76	86757.88	159.68	7087.06	28.89
600 (1, 7.5, 256)	2-DHIFSt	12.27	12.08	28.04	85405.88	160.81	5838.79	31.72
	1-DCDP	16.53	16.53	20.96	89552.25	159.34	6703.23	25.11
	2-DCFS	11.24	10.73	22.53	88738.88	160.28	5145.16	33.33

FOM - Figure of Merit

MDRF - Miss Dist. Rel. to Flight Path

LOT - Lock-On Time (First)

LOR - Lock-On Range (First)

FLOT - Final Lock-On Time

FLOR - Final Lock-On Range

NUPS -Number of Updates

study for processing alone. Thus, analyses could not be completed. However, the data with just imagery processing would have been collected if there had been available time.)

8.3.3 Table 18 presents the data for the same measures given in Table 17 except the data are collapsed over the "best" six of the ten operators as determined by FOM values. It will be recalled that "outrider" data had been discarded in previous studies. This had been done primarily to stabilize the data in order to ensure better equivalence of groups. In Study V, *all* operators executed missions under identical conditions and there were no requirements for grouping operators, etc. One could assume that well-trained operational personnel would have been discarded or "washed out" poor performers before acceptance into the operational environment. In this case, discarding outrider data might be justified. The data in Table 18 eliminate data at the best six of ten level, which was the level at which the changes in values tended to stabilize.

8.3.3.1 In comparing Tables 17 and 18 it can be seen that the elimination of poorer operators' performance substantially reduced FOM values especially at the 300 DR vector and with the exception of this vector a clear distinction among processing techniques is difficult to ascertain. Across vectors, however, it would appear that the 1-DCDP processing technique is the poorest with respect to FOM, FLOR, and NUPS. This is especially true in terms of the wind drift/lock-on bias discussion in para 8.3.2.2. It would also appear that the 2-DCFS technique has a slight advantage over 2-DHIFSt in terms of FLOR and NUPS. With the possible exception of the 150 DR vector, this advantage might be expected to have shown up more clearly in the FOM values if the wind drift/lock-on bias parameters had been present in the simulator.

8.3.4 Based on the data of Study V, the following statement can be made:

8.3.4.1 The three processing techniques evaluated in the presence of jamming can be ordered in terms of operator performance; 2-DCFS .BT. 2-DHIFSt .BT. 1-DCDP. A much broader study on the GBU-15 simulator with the wind drift/lock-on bias parameters present is required to verify this statement.

8.3.4.2 Comparing this statement with that of para 7.7.1.1 based on processing alone, in the presence of jamming the 2-DCFS processing technique reverses its position with respect to the other two techniques (i.e., 2-DHIFSt .BT. 1-DCDP .BT. 2-DCFS). This demonstrates the importance of evaluating image processing techniques under realistic jamming conditions and that operator performance varies depending on the processing technique with and without jamming.

8.4 Recommendation: Up to this point in the program, it is recommended that a flyable version of a video, jam-resistant processor should employ the 2-DCFS processing technique.

9.0 *POTENTIAL STILL TO BE DEVELOPED*

9.1 The work started under the JRIT program needs to be continued. The studies performed to date, merely set the stage for valuable future studies. The areas of effort that still require work are listed as follows:

9.1.1 Explore Bandwidth Parameter Trade-Offs With and Without Jamming: A series of full matrix studies need to be conducted across the more promising processing techniques. These studies would include at least three levels of jamming, a full range of processor settings (on Frame Rate, Bits/Pixel, and Resolution), differing threat configurations (e.g., area, fence, etc.) and with wind drift/lock-on bias simulator parameters.

9.1.2 Measurement of Threat Configuration Effectiveness: As a follow-on to the studies in para 9.1.1, fine grain analyses of specific processing techniques against the full range of operational and future sets of threat (i.e., jammer) configurations need to be performed.

9.1.3 Physics of Other Missions: Other missions such as low altitude penetration/pop-up, high speed vehicle, and multiple strike vehicles (e.g., RPV) need to be explored.

9.1.4 Other Types of Imagery - Such as IR.

9.1.5 Targets and Backgrounds: There is a need to explore the effectiveness of processors with respect to targets of opportunity, target recognition, target types and backgrounds, etc.

9.1.6 Man-Machine Interactive Processing: *Involves the eventual product being* either an existing processing technique, an improved technique, or a hybrid technique. The hybrid technique, for example, might require on-line, real-time manipulation of processing parameters by an operator depending on the ECM threat being encountered.

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APPENDIX
MISSION BRIEFING

Mission Plan Number:

08

Target:

DP & L Power Plant

Launch Parameters:

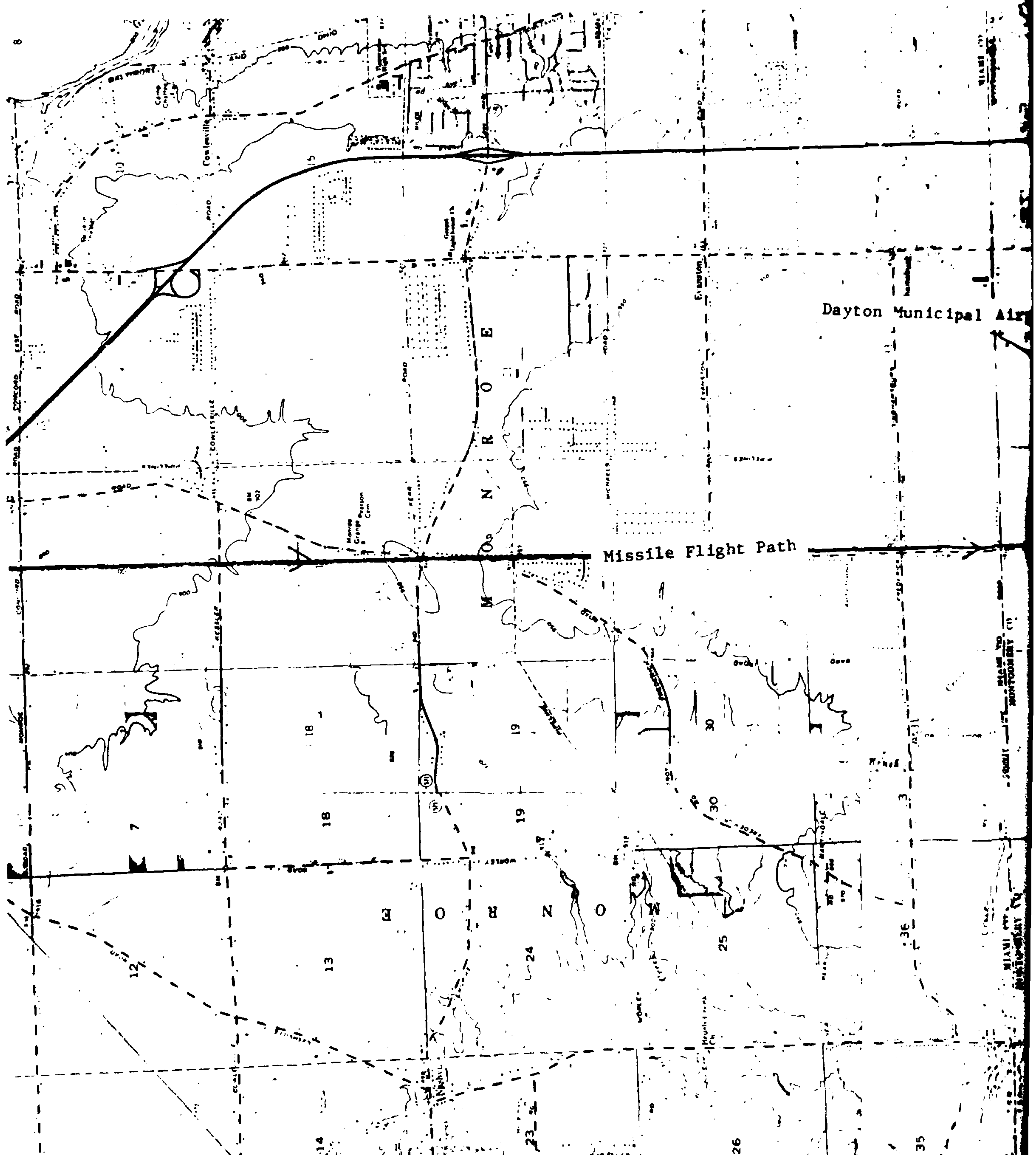
Range: 100,000 ft
Altitude: 20,000 ft
Velocity: 600 ft/sec.
Heading: 180 degrees
Predicted Missile Flight Time: 170 seconds

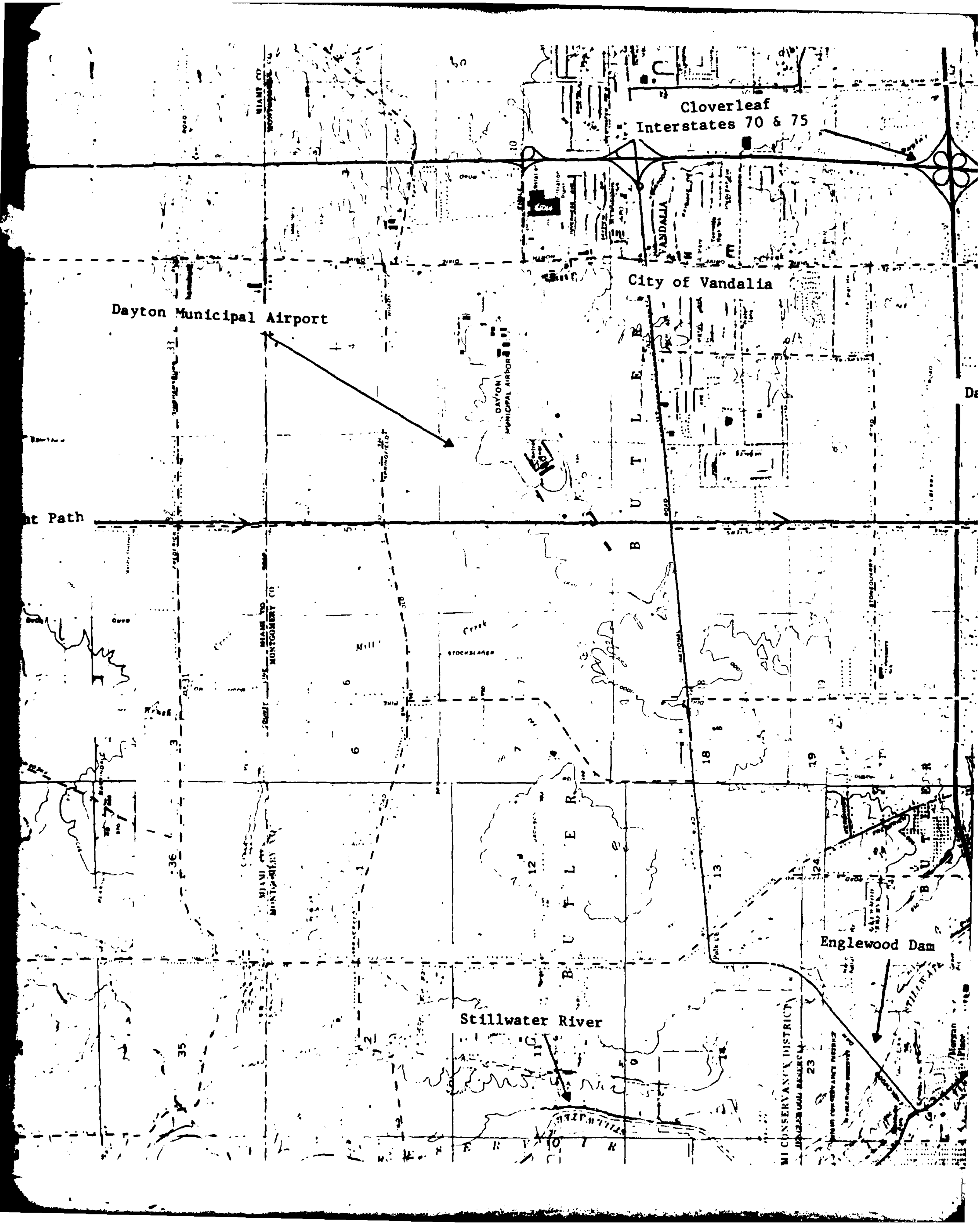
Target Area Description:

The target is the DP & L Power Plant located 1 NM west of the business district in the city of Dayton, Ohio. Specifically, the aiming point is the NW corner of the building nearest the intersection of U.S. 35 and Interstate 75. At video reacquisition, 22 seconds following launch, the target should appear at 13 degrees below the horizon. The first checkpoint is the Dayton Municipal Airport located directly on the missile flight path. The city of Vandalia is just beyond the airport and to the left of the missile flight path. The cloverleaf interchange of Interstates 70 and 75 is very prominent. This interchange is approximately 1 NM south of Vandalia. The Stillwater River can be located at first to the right of the missile flight path. The river flows in a SE direction. The interchange of State Route 48 and Interstate 70 is to the right of the Stillwater River and just beyond the Englewood Dam. The Dayton Memorial Park Cemetary is a good checkpoint, located about 1 NM beyond the cloverleaf interchange of Interstates 70 and 75. A drive-in theater can be seen approximately 1.5 NM beyond (south of) the Dayton Memorial Park Cemetery. Approximately 1 NM to the left of the missile flight path is the merging of two prominent rivers, the Stillwater and the Great Miami. This is about 1.5 NM NE of the target. The target, DP & L Power Plant, is adjacent to the far side of a railroad track (Penn Central).

Photograph of Target

U.S. GOVERNMENT PRINTING OFFICE 1981 757-002/67


Dayton Municipal Air
Missile Flight Path


Cloverleaf
Interstates 70 & 75
City of Vandalia
Dayton Municipal Airport
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Englewood Dam
Stillwater River
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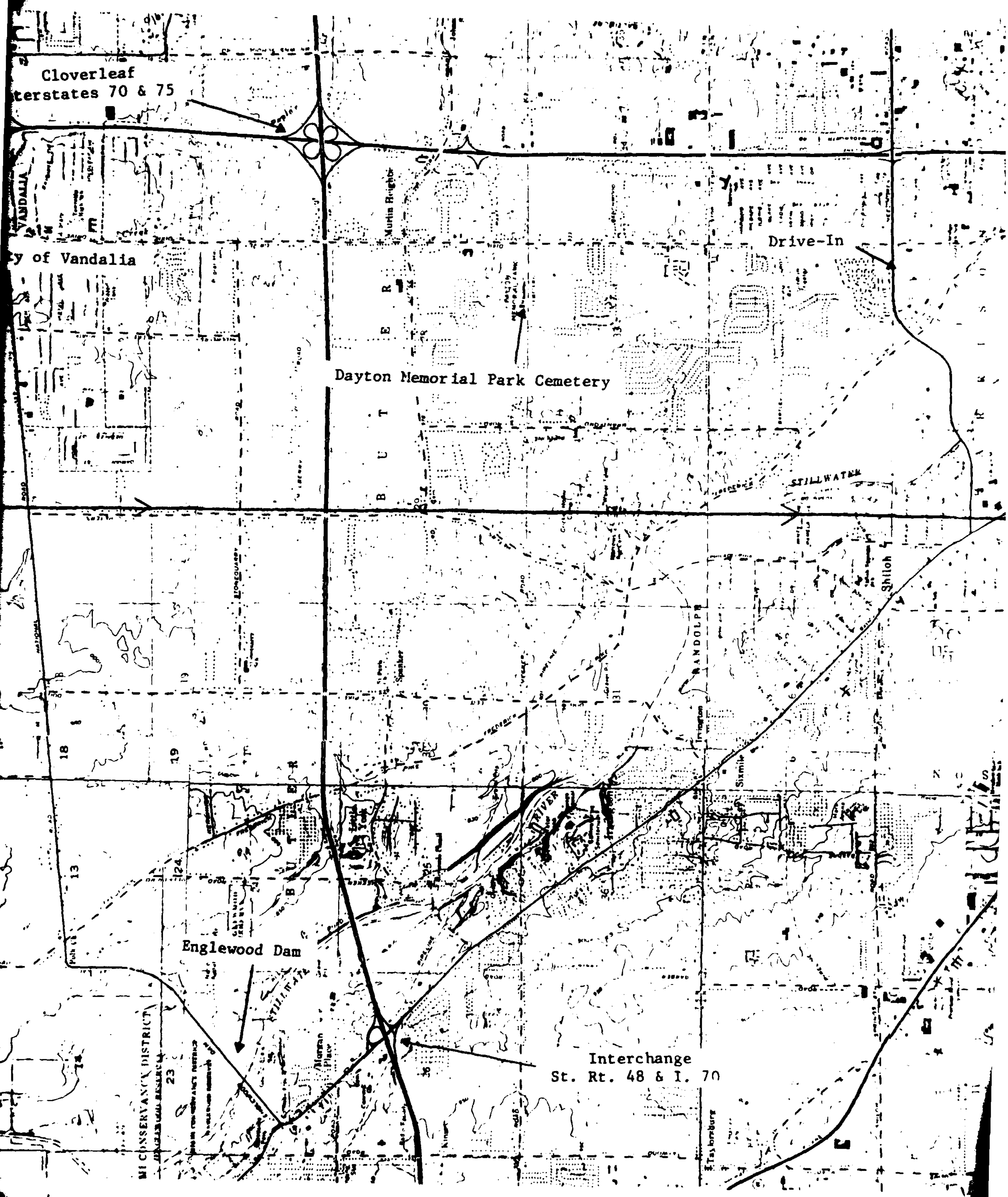
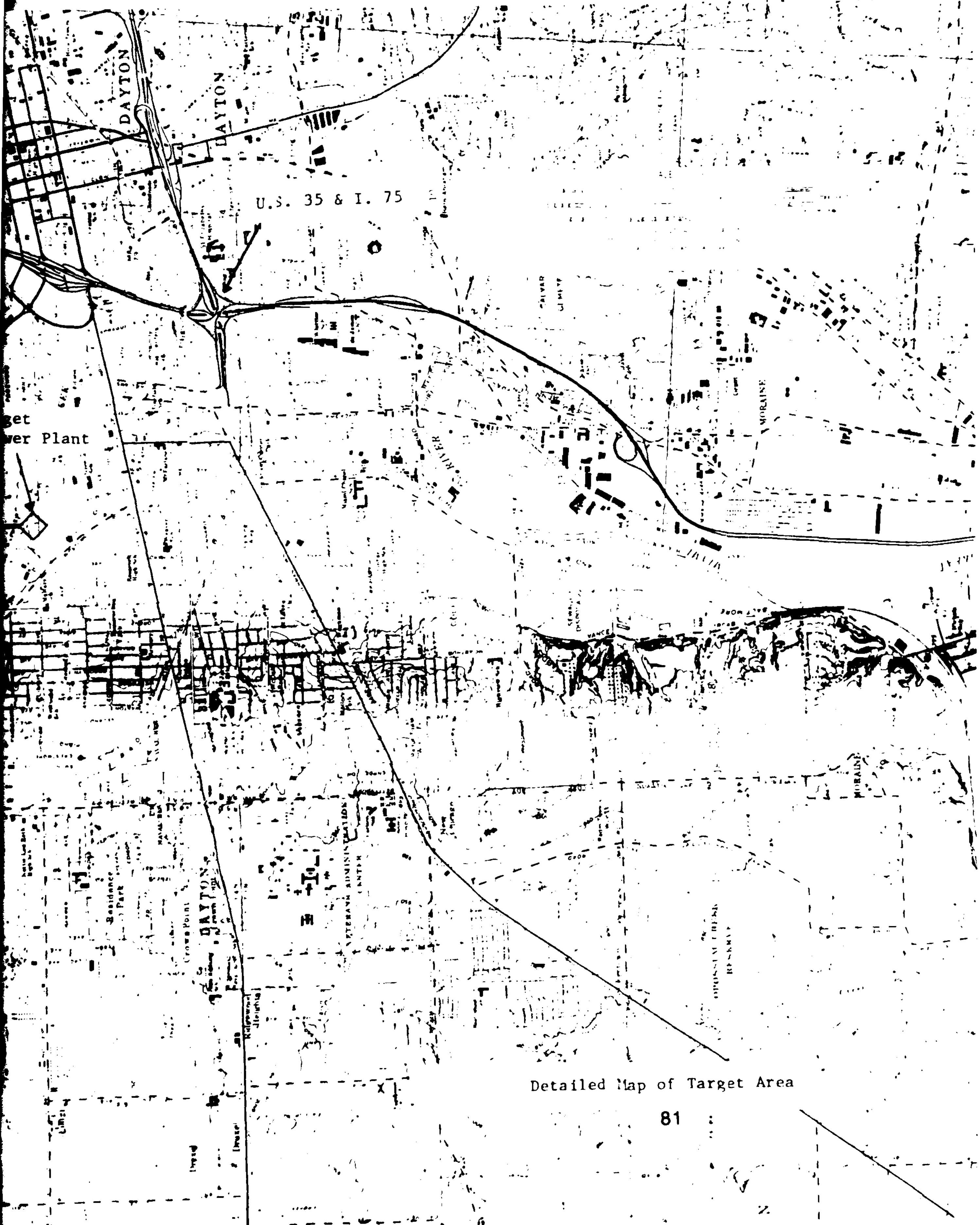

Cloverleaf
terstates 70 & 75
y of Vandalia
Drive-In
Dayton Memorial Park Cemetery
Englewood Dam
Interchange
St. Rt. 48 & I. 70


Stillvater & Gr. Miami Rivers
Drive-In
Target
DP & L Power Plant
Penn Central Railroad Track
STILLWATER
Shiloh
DAYTON



Detailed Map of Target Area